We got it, but what is it?
The new boson as seen from CMS

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CMS Public Results:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults (click on Higgs Physics Analysis Summaries)

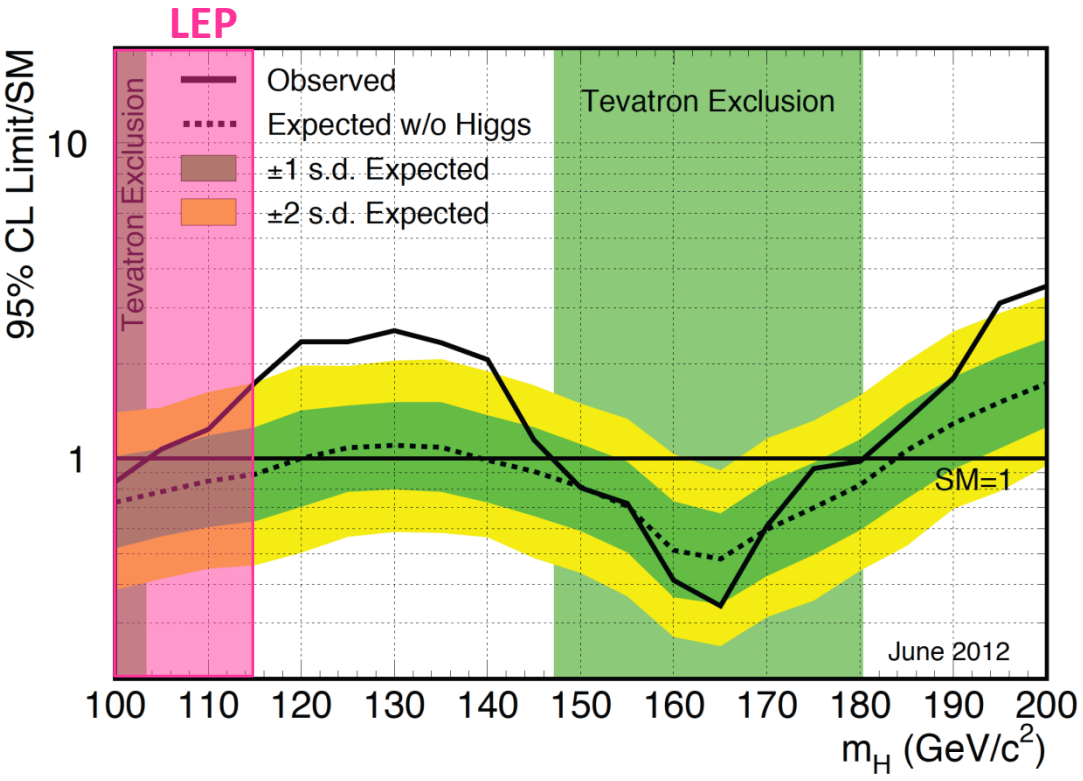
Unless otherwise stated, all results shown here include all 7+8 TeV data

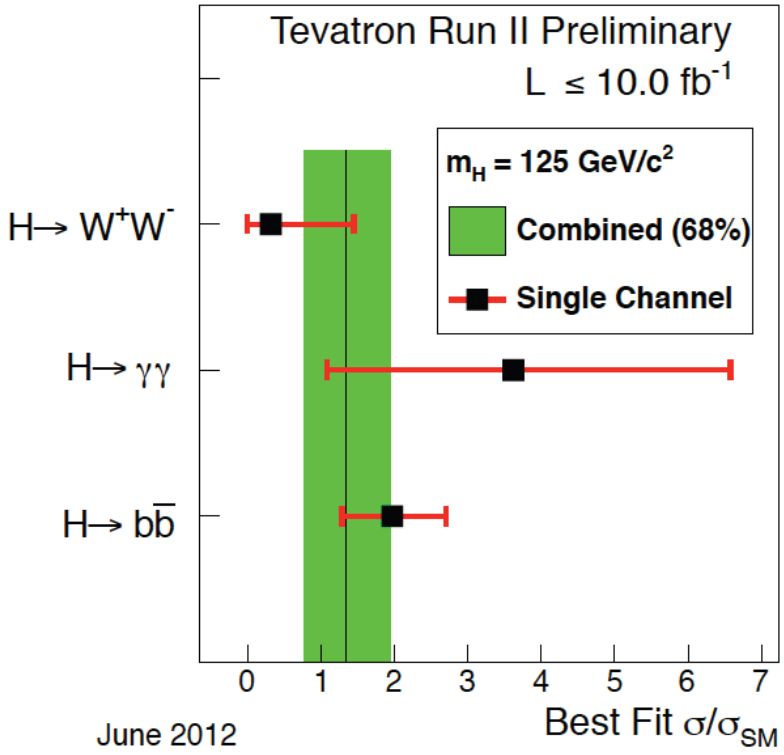
Brief Introduction

Tevatron Results (ICHEP 2012)

Expected	Observed
100-120 GeV	100-103 GeV
139-184 GeV	147-180 GeV

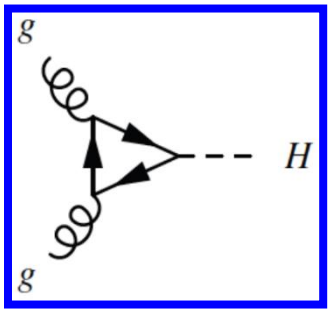
S. Shalhout (ICHEP 2012)



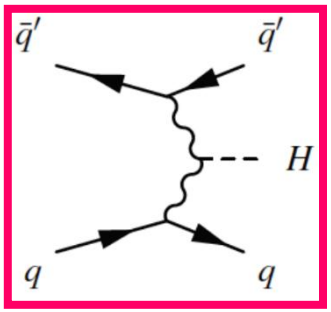


Channels	Local	Global
All Tevatron	3 σ	2.5 σ
H→bb	3.2 σ	2.9 σ

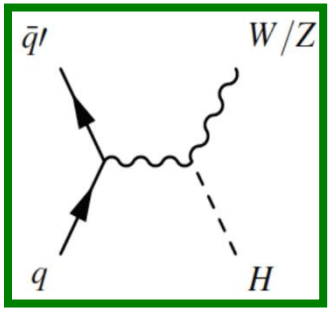
SM Higgs Production at the LHC



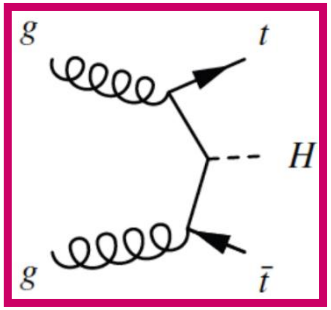
Gluon Fusion



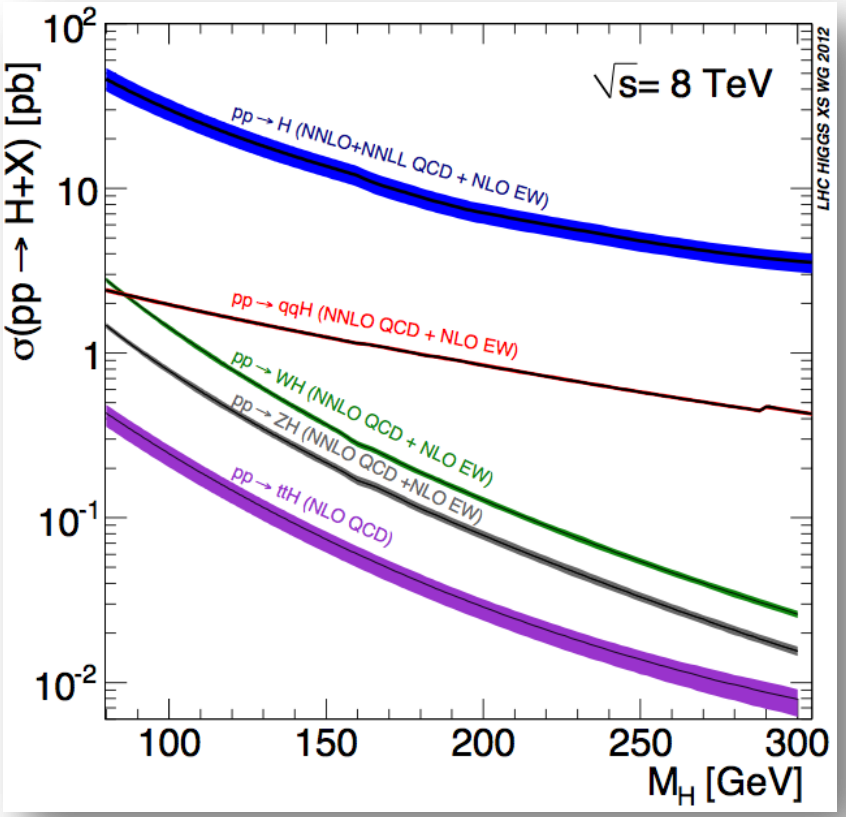
Vector-Boson Fusion



Higgs-strahlung



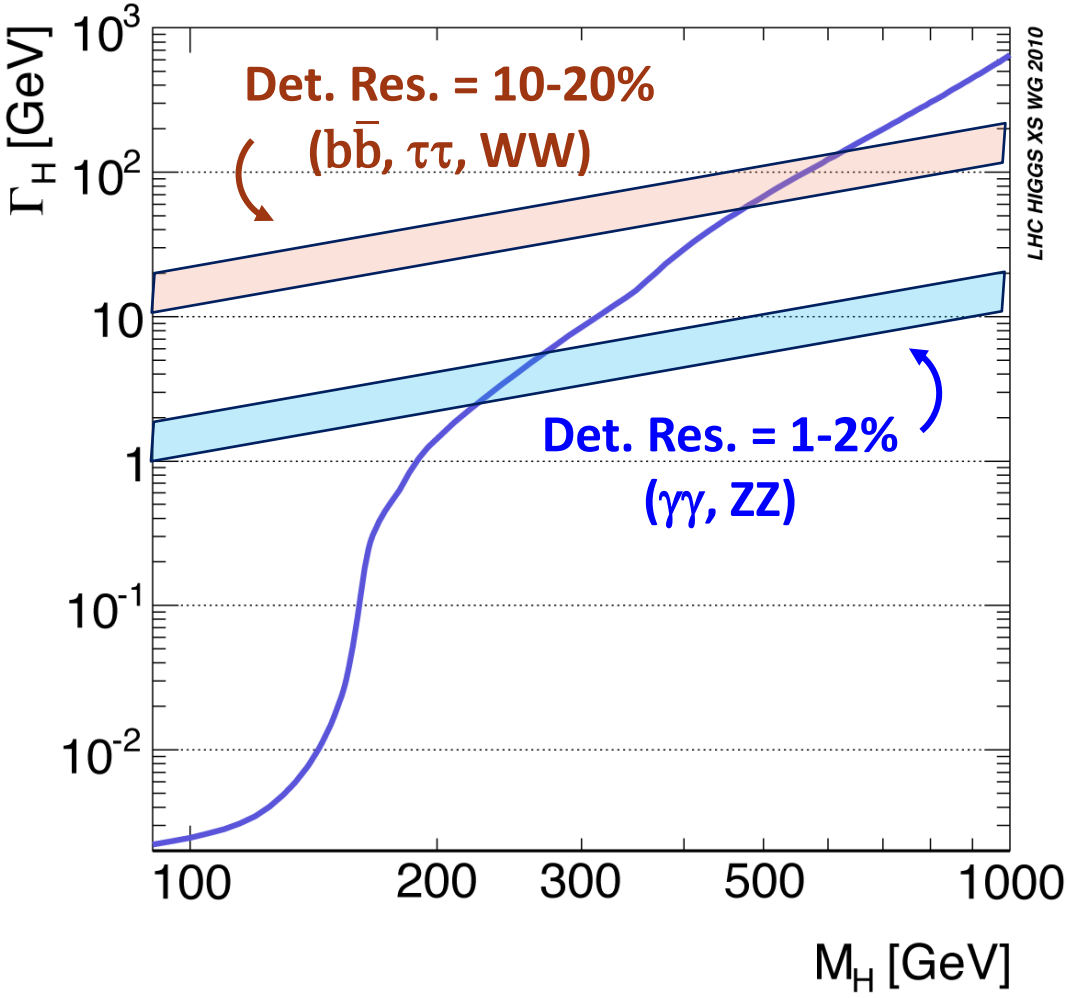
Top Fusion ($t\bar{t}H$)



LHC in 2012, at record luminosity (7 x 10^{33} $cm^{-2}s^{-1}$) and energy (8 TeV), is now producing SM Higgs bosons (M_H = 125 GeV) at a rate **~750/hr**

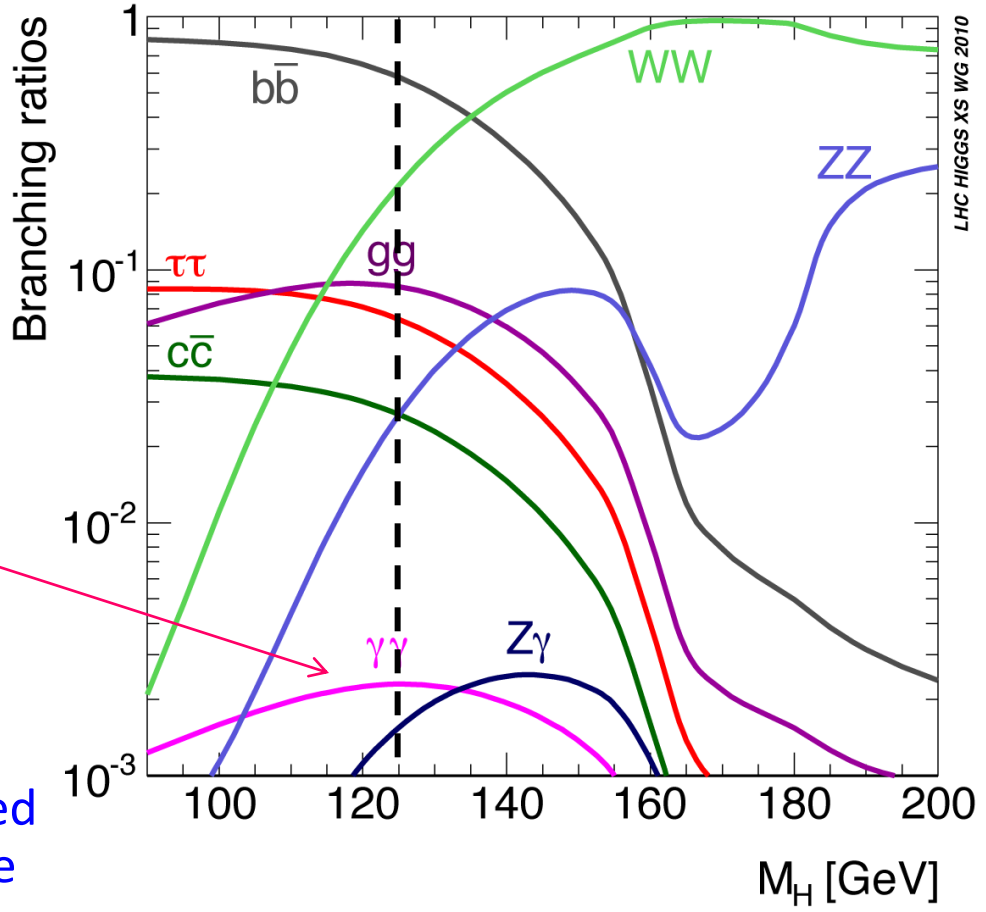
What does the SM Higgs look like?

- **Low mass**
  - Narrow peak in $\gamma\gamma$, ZZ(4l)
  - Observed width dominated by *detector resolution*
- **High mass**
  - Higgs becomes a broad resonance dominated by *natural width*
  - Theory input is critical

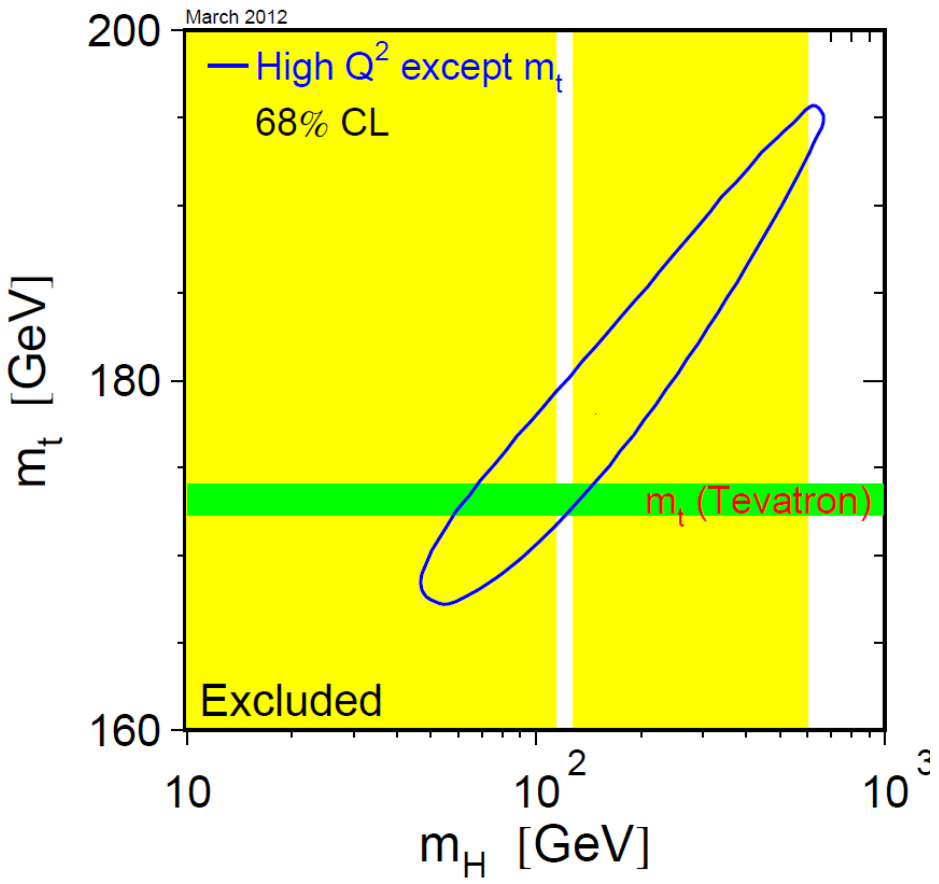


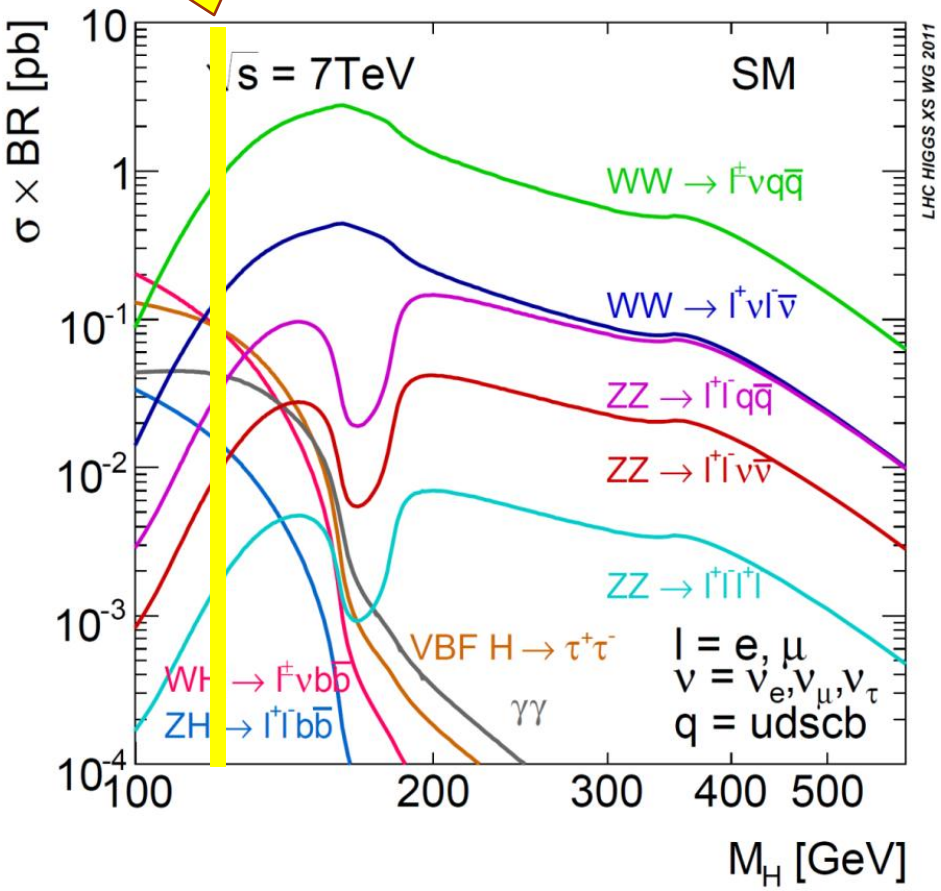
Partial Widths

- **Favorite daughters for $M_H = 125$ GeV:**
  - $b\bar{b} = 58\%$
  - $WW = 22\%$
  - $\tau\tau = 6.3\%$
  - $ZZ = 2.8\%$
  - $\gamma\gamma = 0.2\%$
- **Did we discover it in one of its least favorite modes?**
  - Using particles that do not even couple to the Higgs?
  - All accessible channels are needed to determine precisely the nature of the new particle



Nature has been kind!

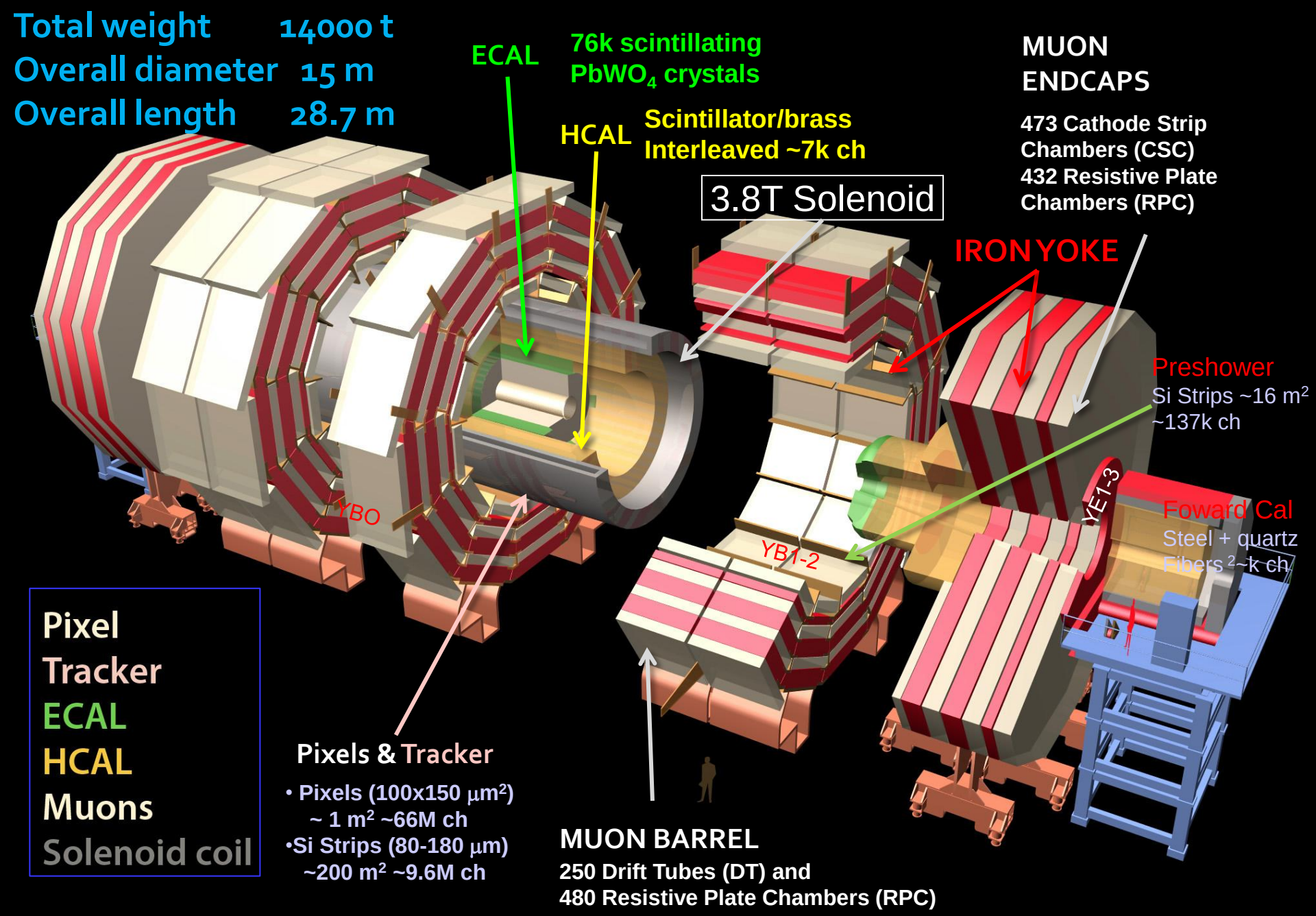




Only region in M_H where

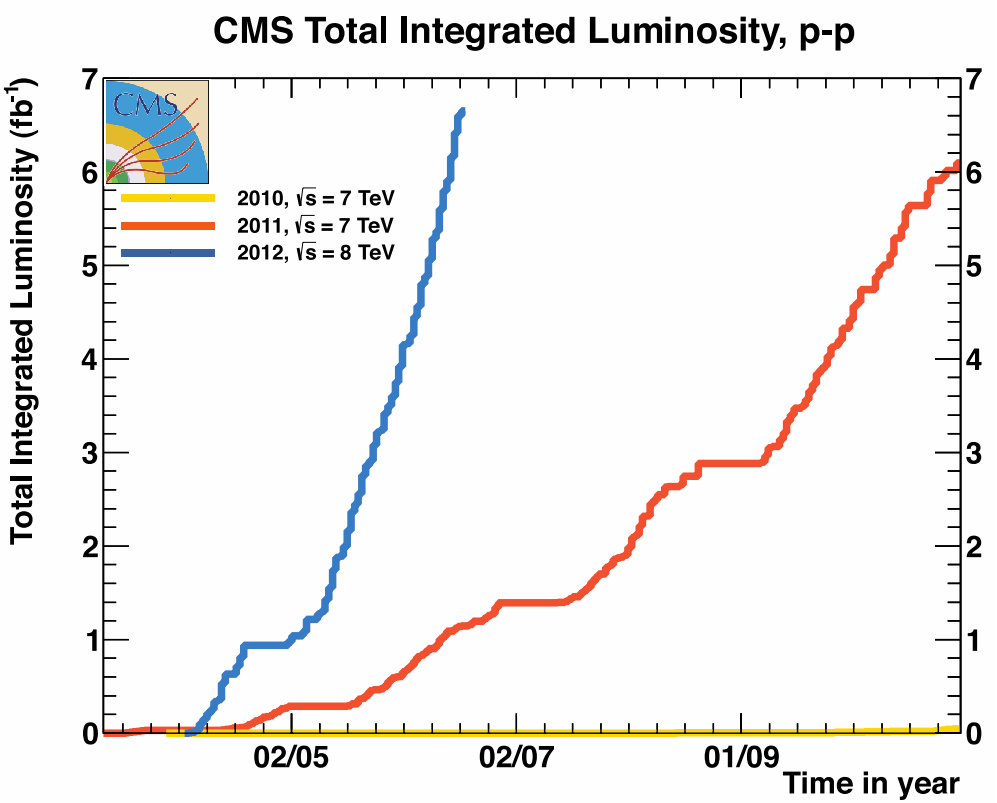
- **Cross sections are large**
- **Fermion final states (bb+ττ) are accessible**
- **Natural width is negligible**

Detector and Performance


Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m
ECAL
76k scintillating PbWO4 crystals
HCAL
Scintillator/brass Interleaved ~7k ch
3.8T Solenoid
MUON ENDCAPS
473 Cathode Strip Chambers (CSC)
432 Resistive Plate Chambers (RPC)
IRON YOKE
Preshower
Si Strips ~16 m2
~137k ch
Foward Cal
Steel + quartz Fibers ~2k ch
YBO
YB1-2
YE1-3
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm2) ~ 1 m2 ~66M ch
•Si Strips (80-180 μm) ~200 m2 ~9.6M ch
MUON BARREL
250 Drift Tubes (DT) and
480 Resistive Plate Chambers (RPC)
Total weight 12500 t, Overall diameter 15 m, Overall length 21.6 m, Magnetic field 4 Tesla

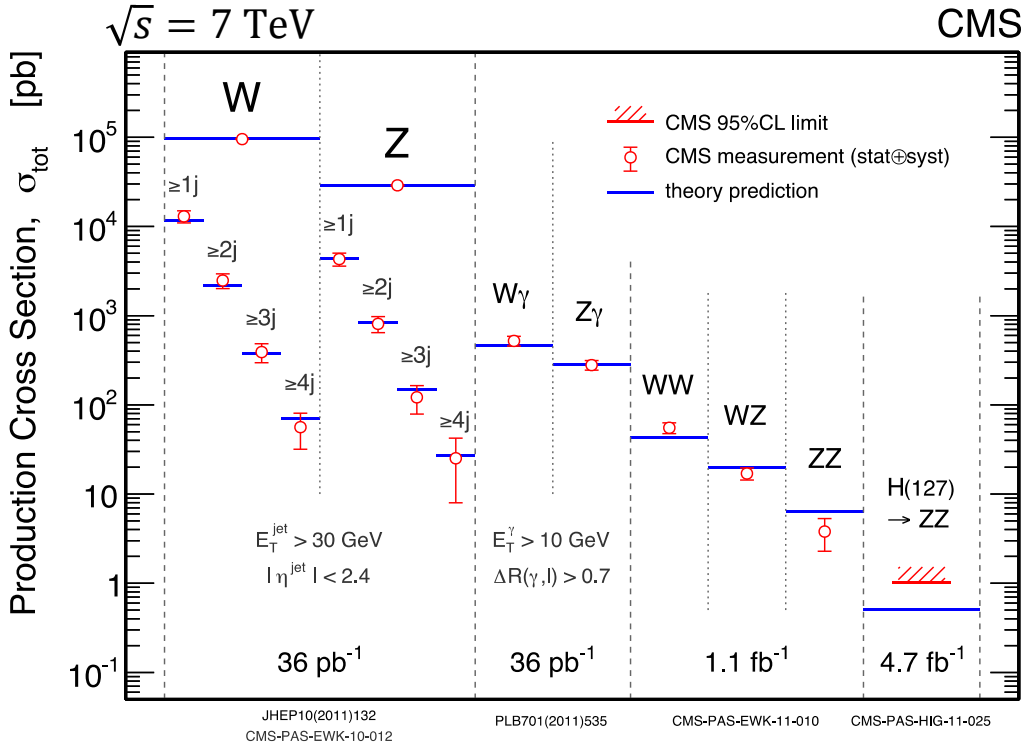
LHC + CMS Performance

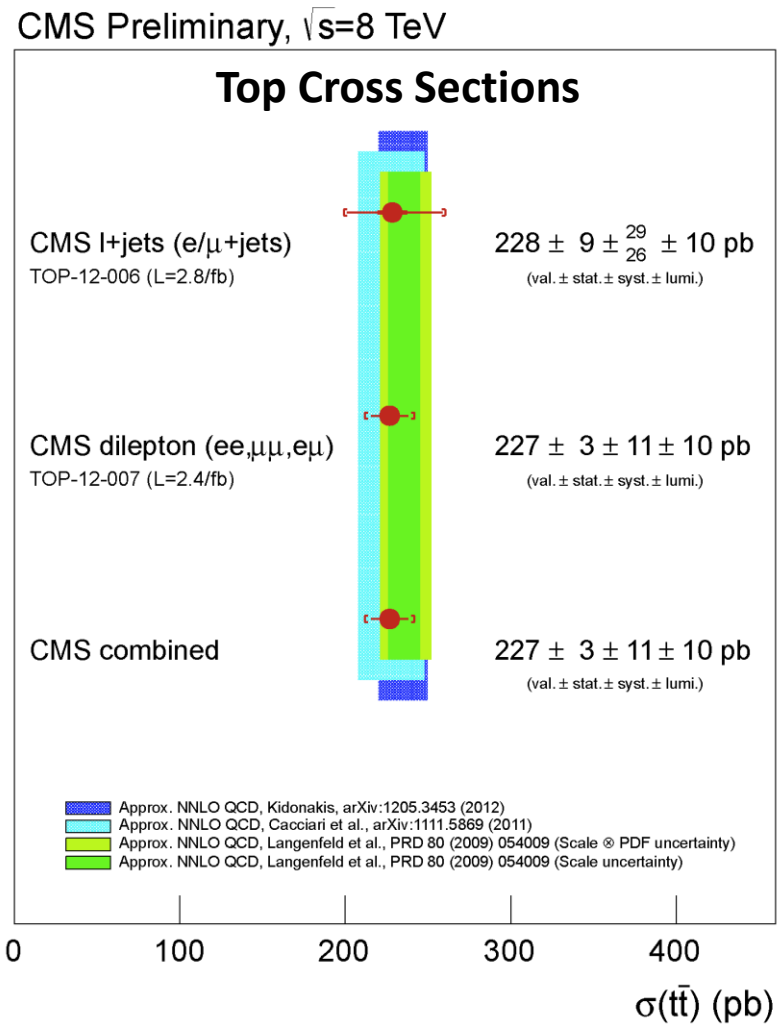
Higher energy (4 TeV per beam) and higher luminosity (> 7e33)



- **Phenomenal performance**
  - Record luminosity (> 5e33) achieved shortly after startup
  - Sustained rate of > 1.5fb^{-1} /wk
  - Total delivered exceeds 6 fb^{-1}
- **Challenging conditions**
  - Average pile-up 10-30
  - Triggers are working as or better than predicted
  - Online efficiency > 90%

Standard Model @ CMS

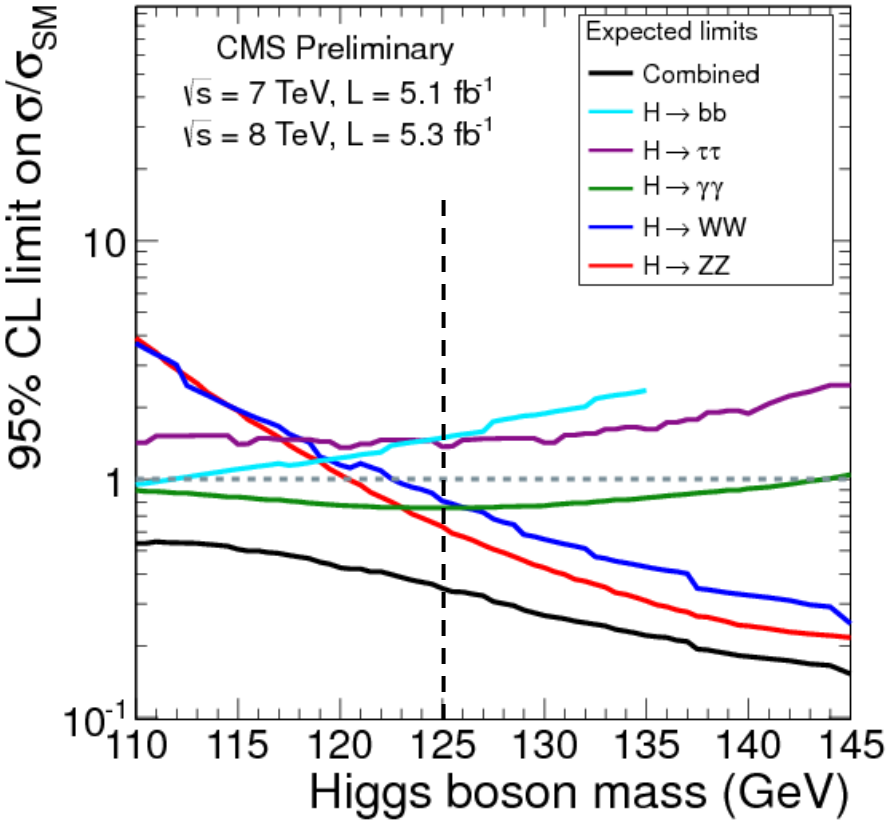




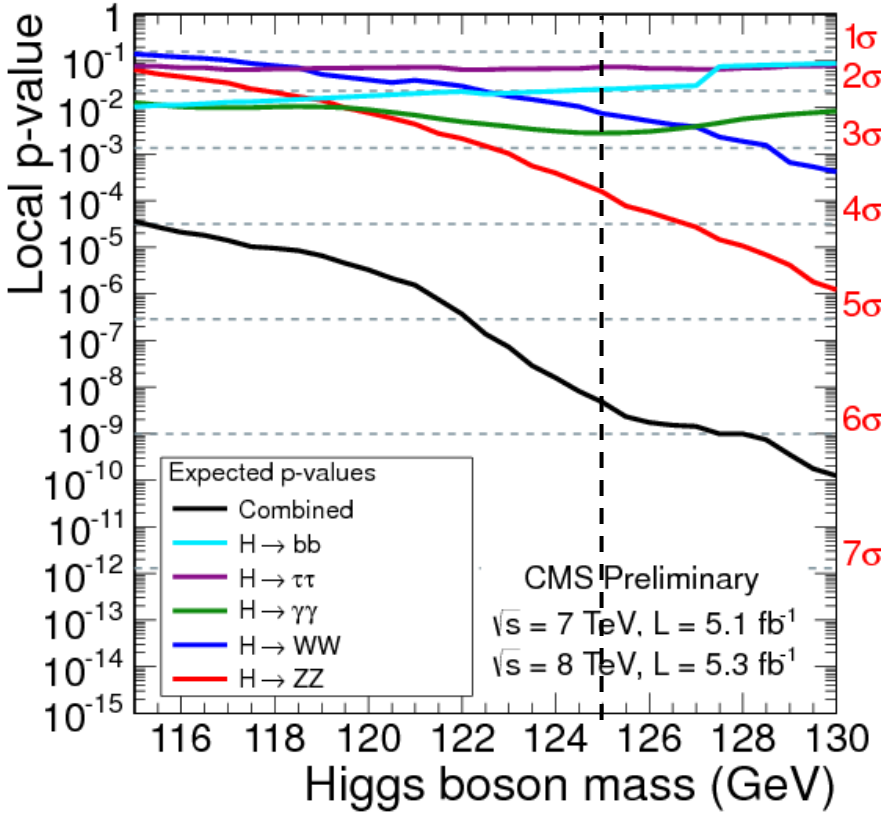
~70 papers published or in preparation on SM physics at 7 and 8 TeV. No deviations from predictions have been observed.

Higgs Search Sensitivity @ CMS

95% CL Exclusion



Discovery Potential



@ 125 GeV:

- All boson channels are below SM sensitivity for exclusion
- Combination of fermion channels ($\tau\tau$ + bb) is at SM sensitivity for exclusion
- Full combo sensitive at all masses, expected discovery significance is just below 6σ

General Comments on CMS Higgs Searches

Blind analysis methods are used in all CMS Higgs searches

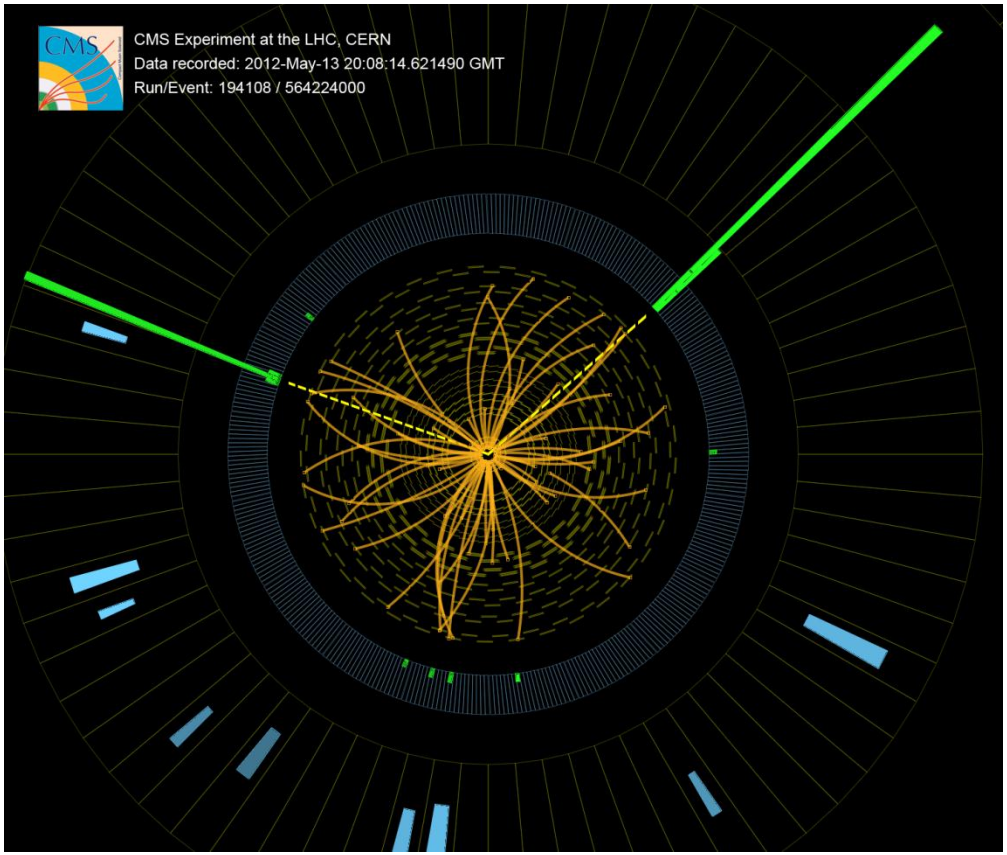
We search **explicitly** for the SM Higgs boson: each analysis at CMS uses unique properties of the SM Higgs boson to optimize their search sensitivity relative to known SM bkgs

This means that analyses are **model dependent** to varying degrees , and the significance of an observed excess is within the context of a search for the SM Higgs boson

However, it does **not** mean that a 5σ signal proves that what we have seen is the SM Higgs boson

Bump Hunting: H $\rightarrow \gamma\gamma$, ZZ

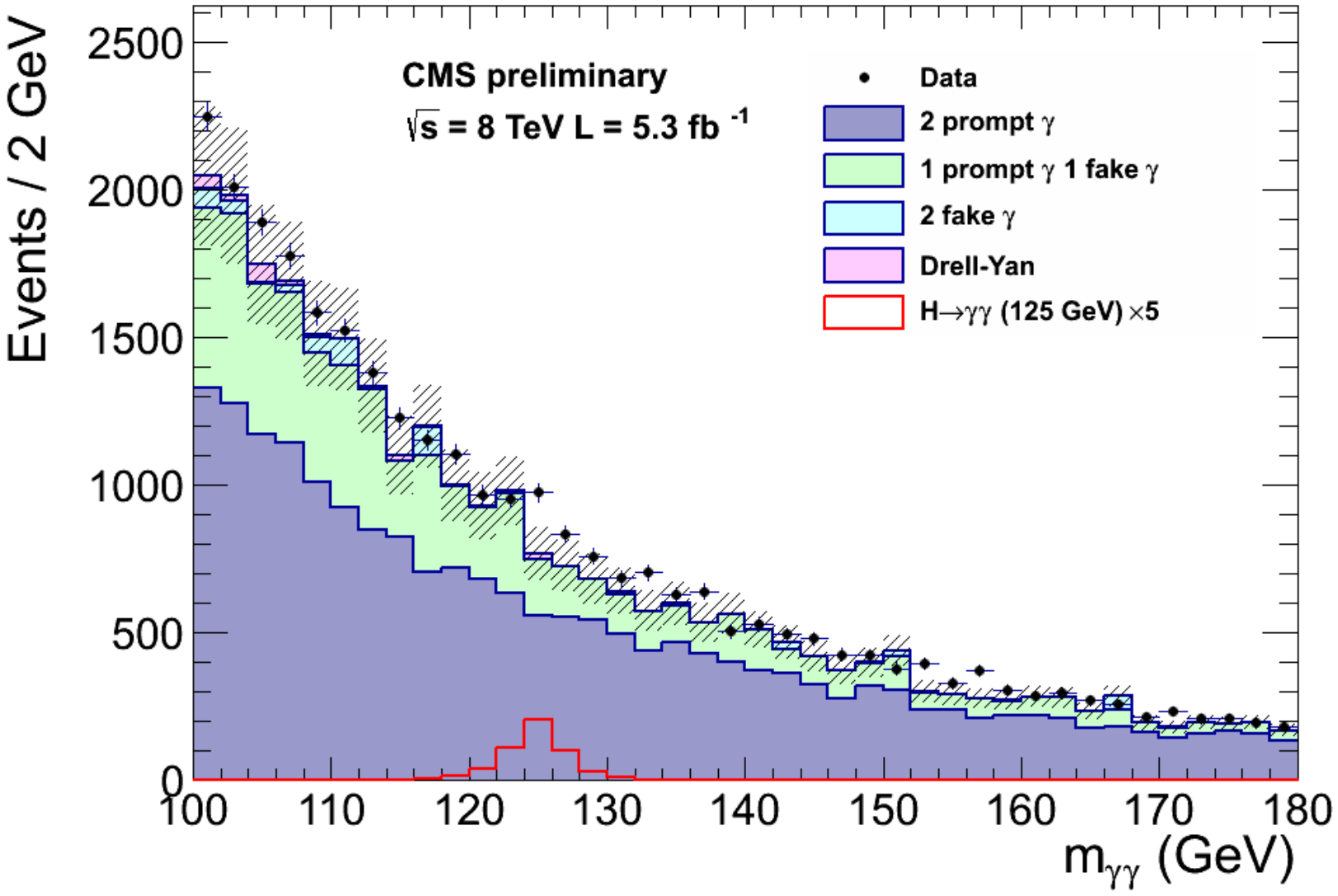
Overview of Search for $H \rightarrow \gamma\gamma$



Analyzed data: 5.1fb^{-1} @ 7 TeV, 5.3fb^{-1} @ 8 TeV

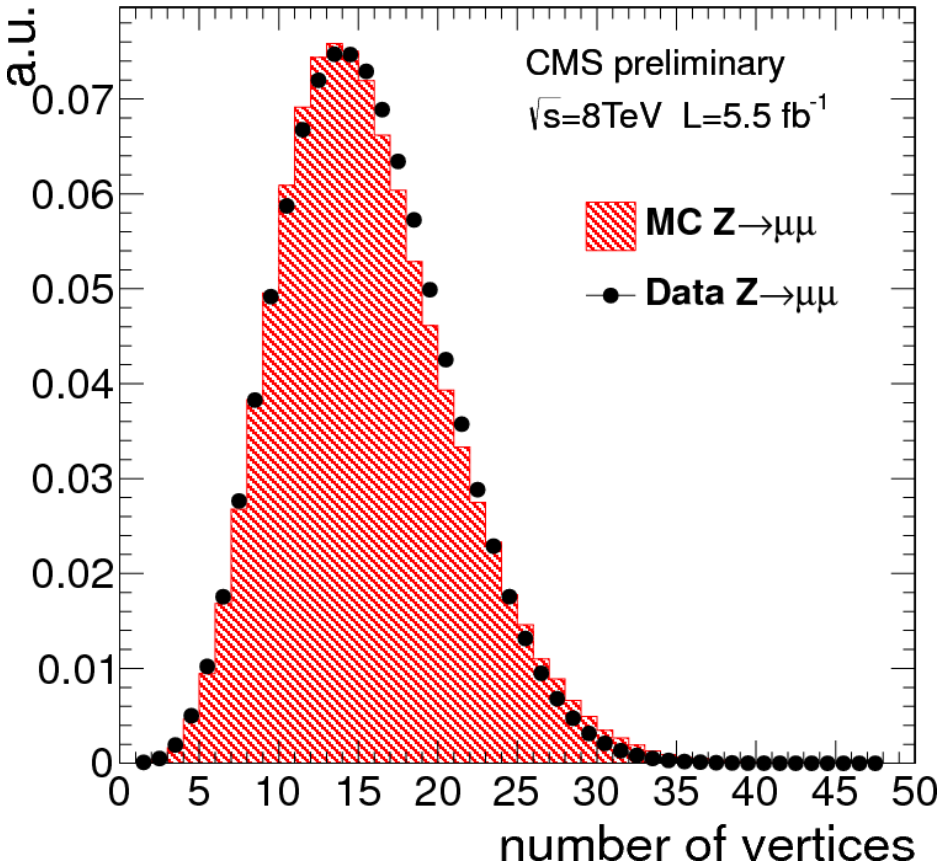
- **Experimental signature**
  - Narrow diphoton resonance
  - Hard diphoton p_T spectrum
  - Isolated photons
  - VBF: spectacular diphoton+dijet
- **Analysis strategy**
  - MVAs to select photons and categorize events
  - Mass fit in 4+2 categories with background model from data
  - Cross-checks
    - MVA sideband analysis
    - Simple cut-based analysis

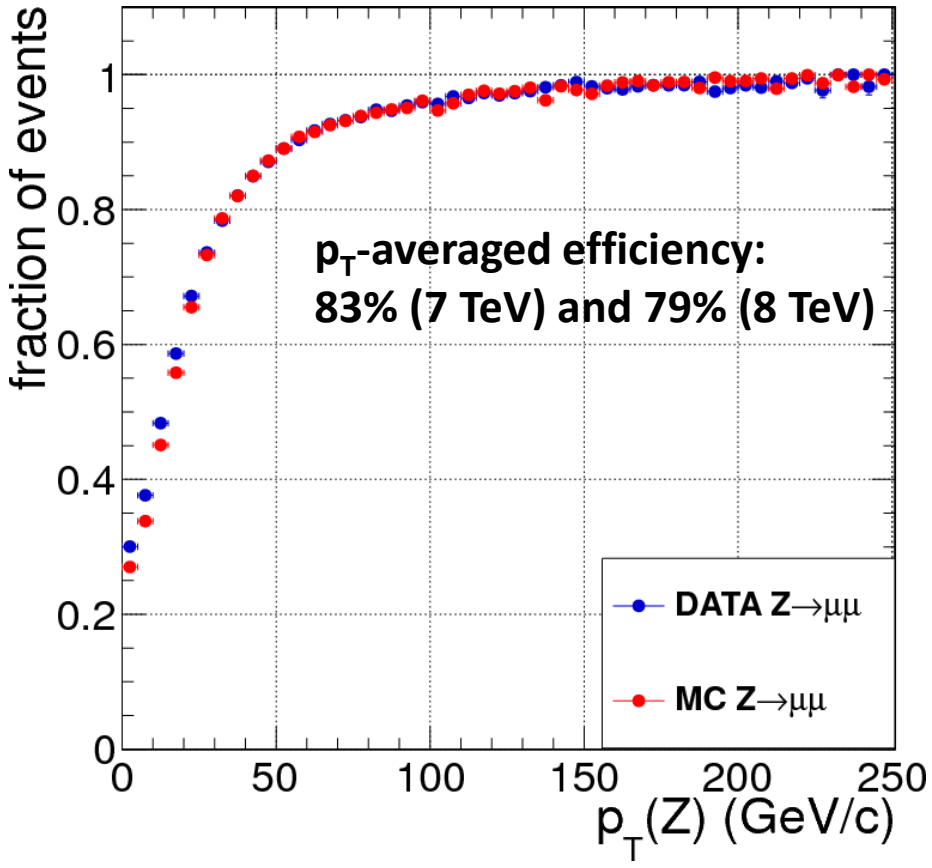
Diphoton Backgrounds



Vertex Selection

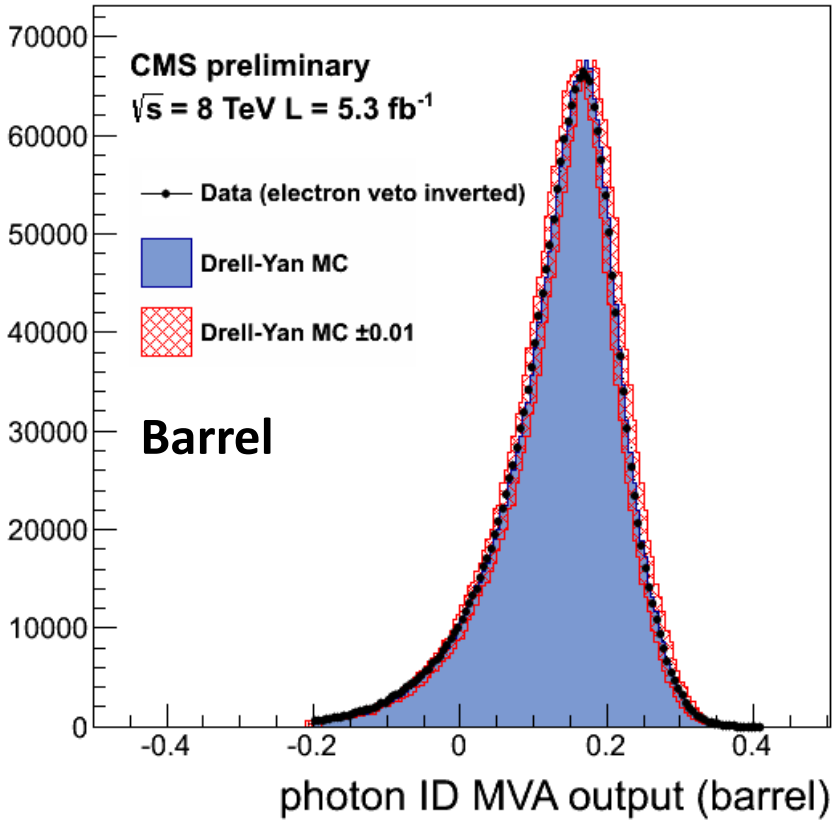
- **Proper selection of pp interaction vertex is critical**
  - Mean number of interactions per crossing was 9.5 (18.7) in 7 (8) TeV data
  - **Mass bias and resolution depend on correct vertex ID and position resolution**
  - A BDT is trained to identify the correct vertex based on kinematics and topology
  - Performance of the vertex selection is checked on $Z \to \mu\mu$ events in data

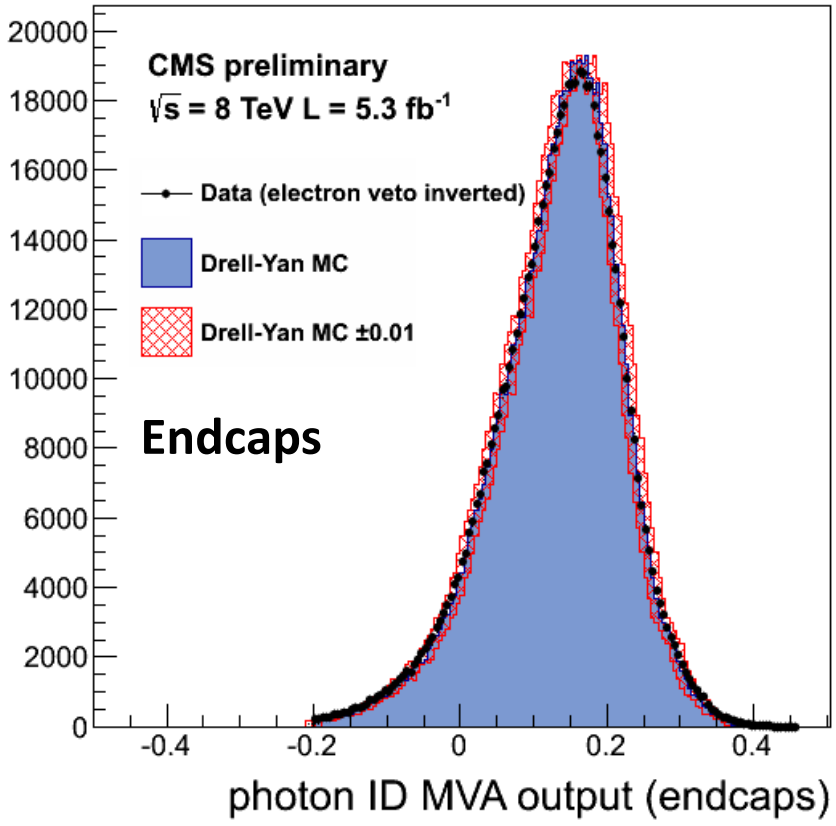




Photon Selection

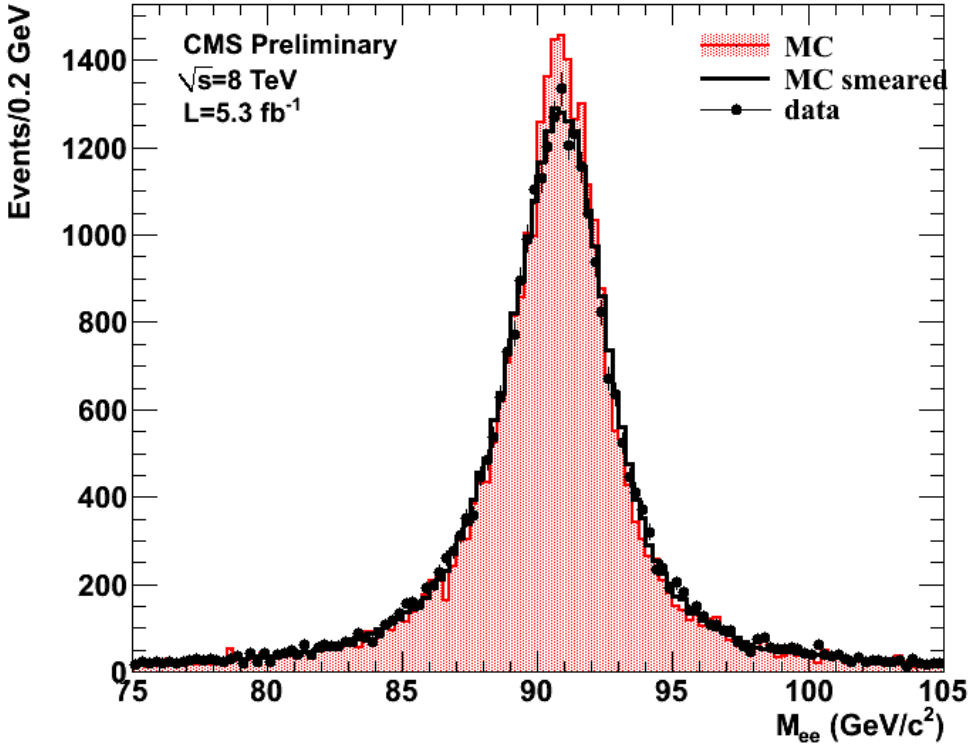
- Trigger:
  - two photons with tight/loose criteria
- Photons:
  - $p_T^{\gamma 1} > m_{\gamma\gamma}/3, p_T^{\gamma 2} > m_{\gamma\gamma}/4$
  - $|\eta| > 2.5$, excluding barrel/endcap gap
  - Select pair with highest scalar $\sum p_T$
- MVA selection:
  - Trained to reject fakes using observed shower-shape differences, isolation, and photon pseudorapidity
  - Efficiency, measured in $Z \rightarrow ee$ data events, is typically > 97%

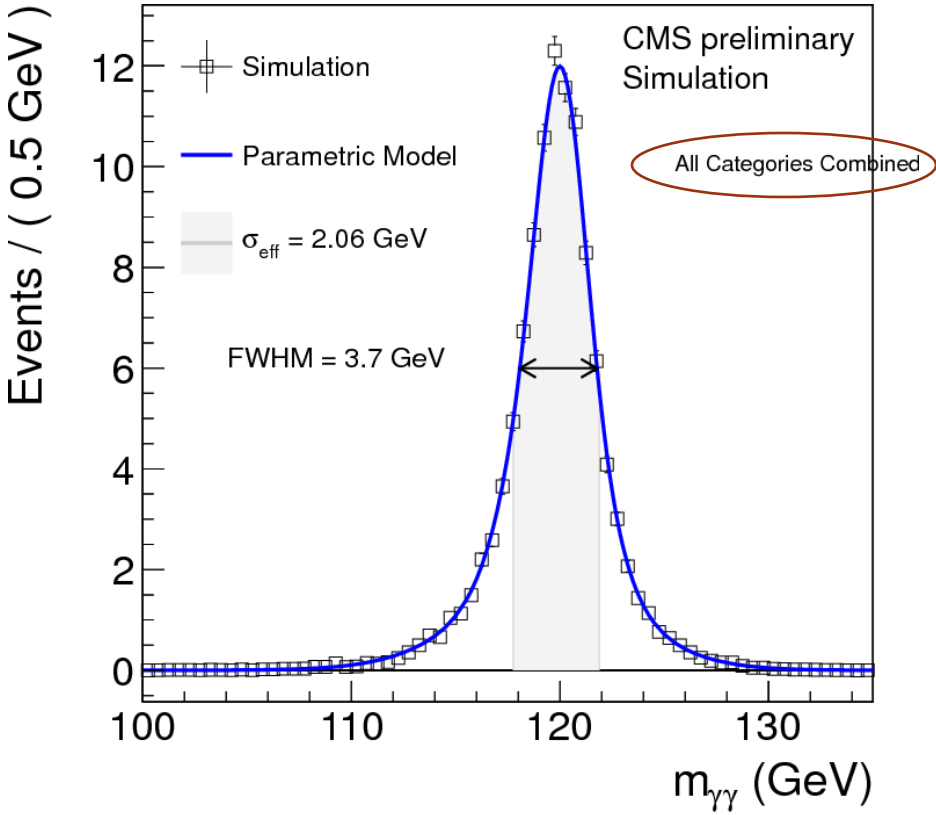




Photon Energy and Signal Model

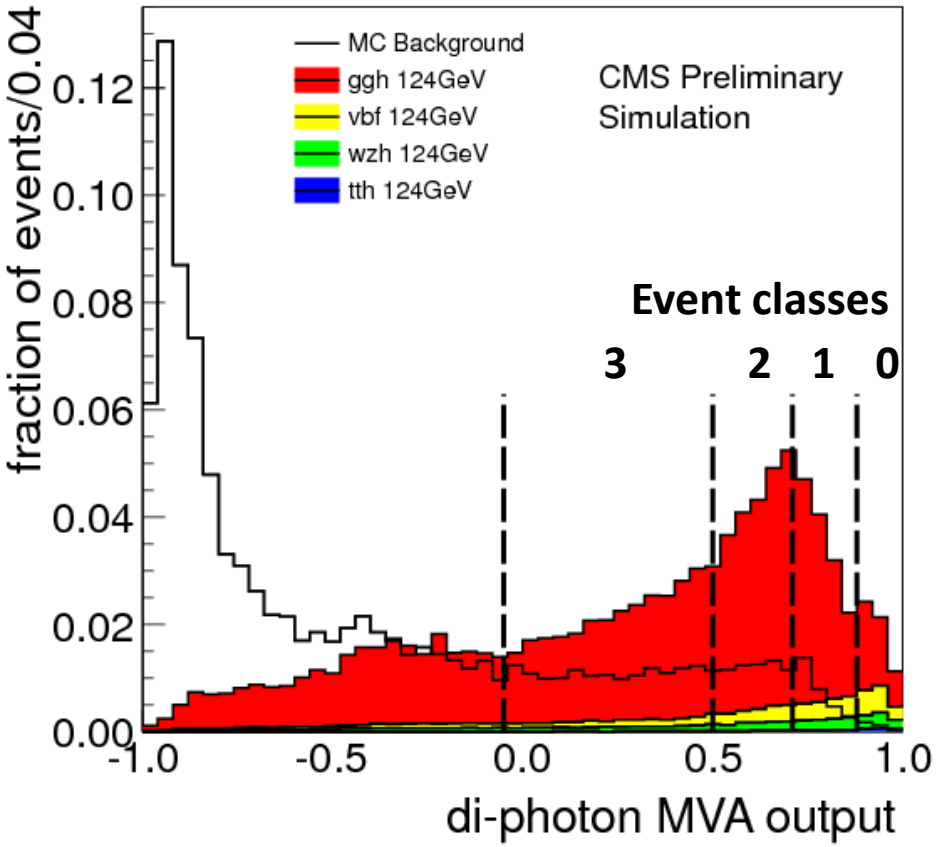
- **Residual photon energy corrections derived from MVA regression**
  - Trained on signal MC using photon position and shower shape
  - Additional smearing derived from $Z \rightarrow ee$ events in data
- **Signal $m_{\gamma\gamma}$ model built from simulation corrected by data**
  - Resolution is approximately 2 GeV averaged over all signal events

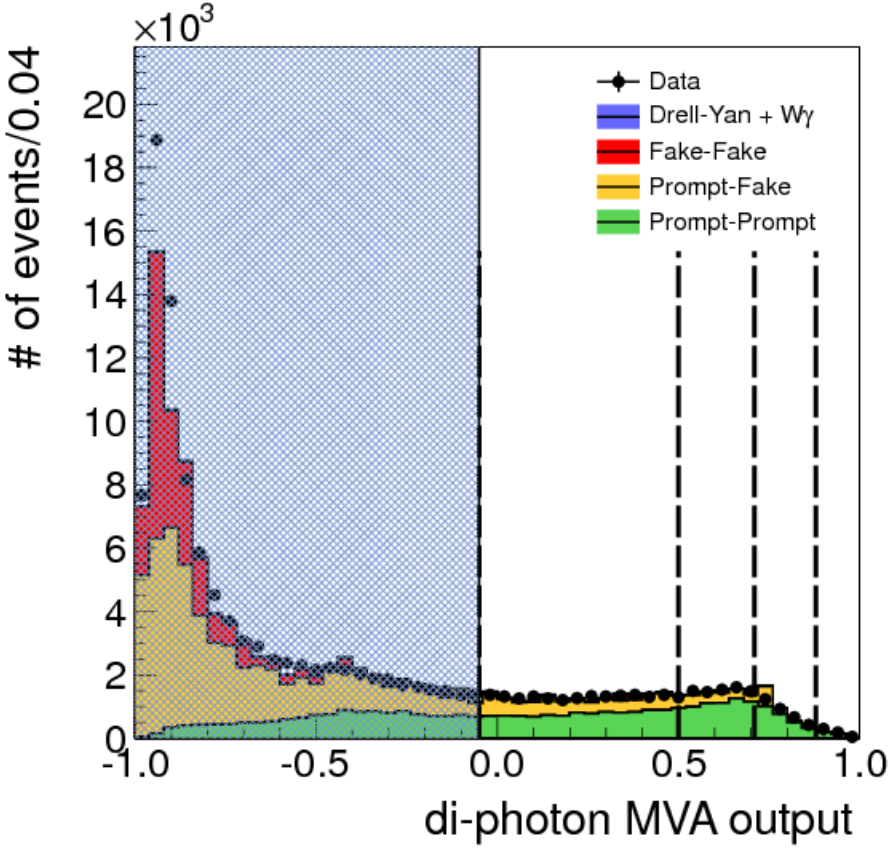




Diphoton Selection

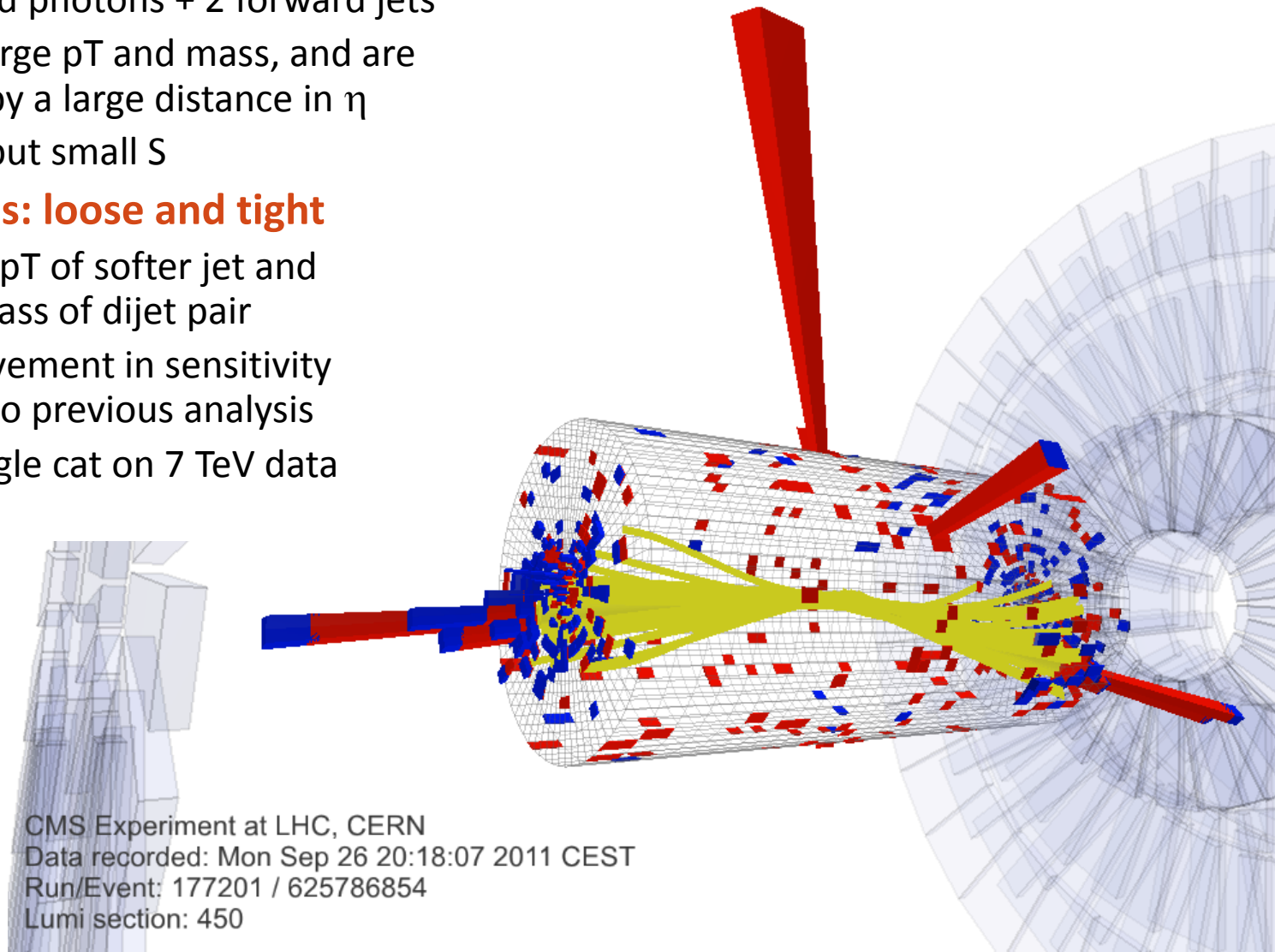
- **Yet another MVA is used to select diphoton events**
  - Trained to separate SM Higgs signal vs. background
  - Inputs: photon p_T, η, and MVA output, $\cos\Delta\phi_{\gamma\gamma}$, and per-event mass resolution
  - Output checked on data, residual differences included in systematic uncertainties
  - Four event classes are defined by the diphoton MVA output



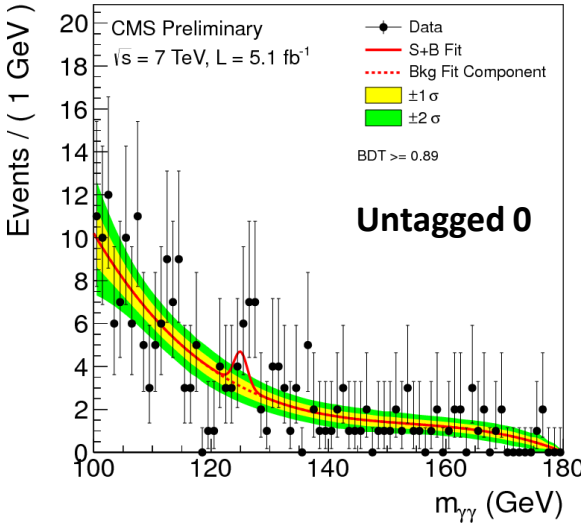


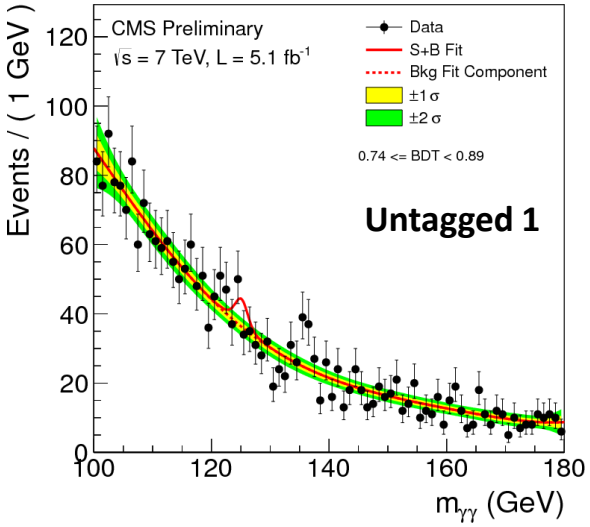
VBF Categories

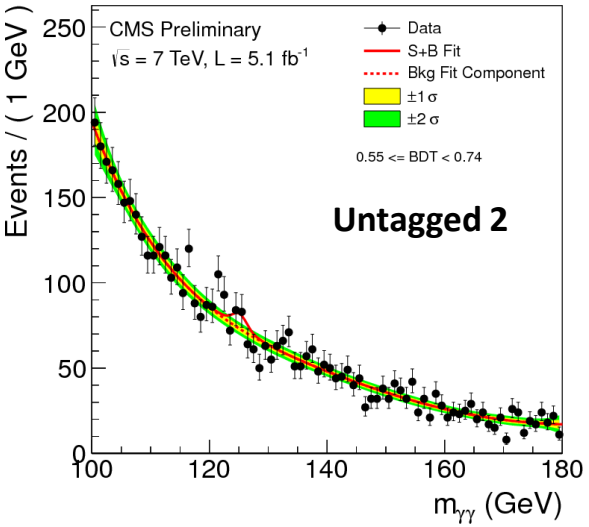
- **Select events with VBF topology**
  - Two isolated photons + 2 forward jets
  - Jets have large pT and mass, and are separated by a large distance in η
  - Large S/B, but small S
- **Two categories: loose and tight**
  - Defined by pT of softer jet and invariant mass of dijet pair
  - 15% improvement in sensitivity compared to previous analysis
  - Still use single cat on 7 TeV data

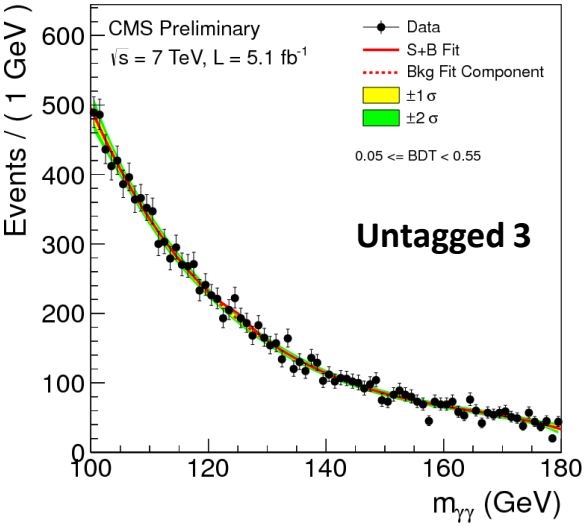


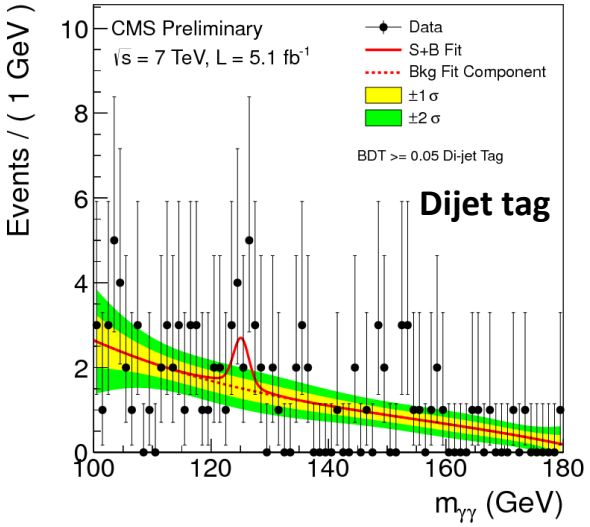
7 TeV Mass Distributions





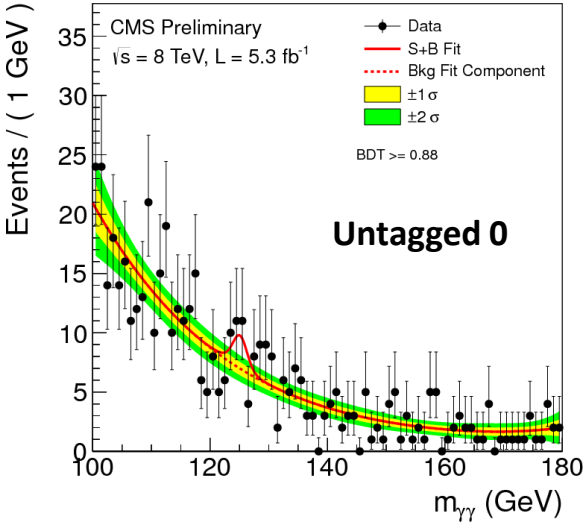


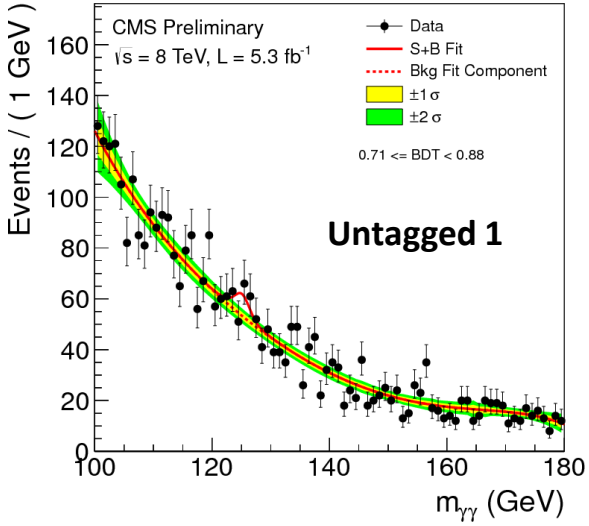


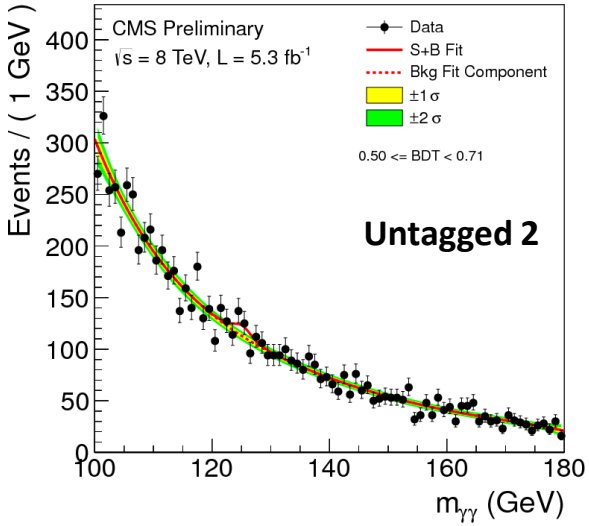


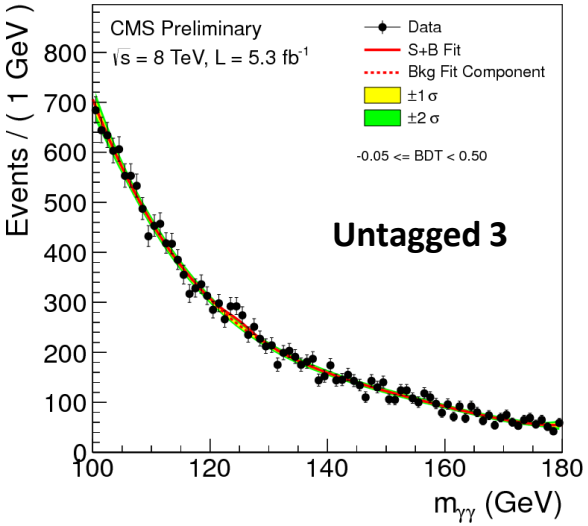
- **Background model**
  - Simultaneous S+B fit to mass distribution in all categories category
  - Background taken to be polynomial (3rd, 4th, or 5th degree) determined by keeping bias below 20% of statistical error on signal

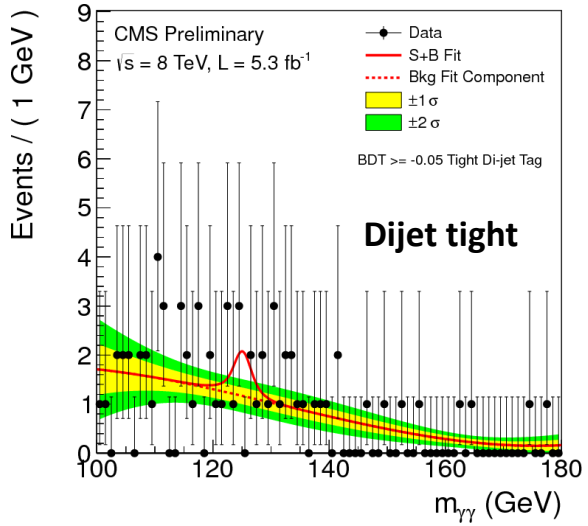
8 TeV Mass Distributions

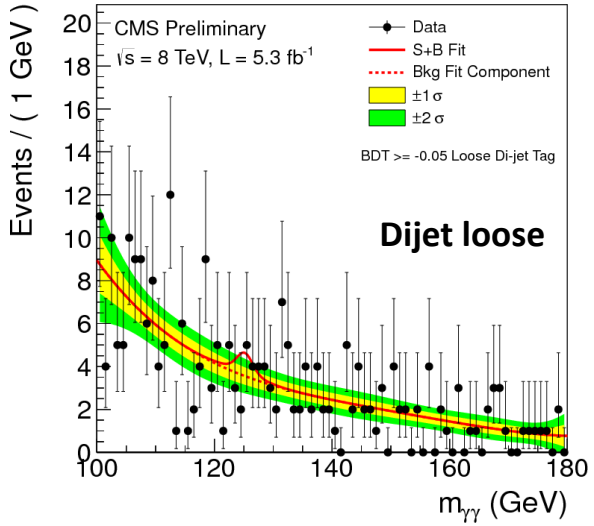




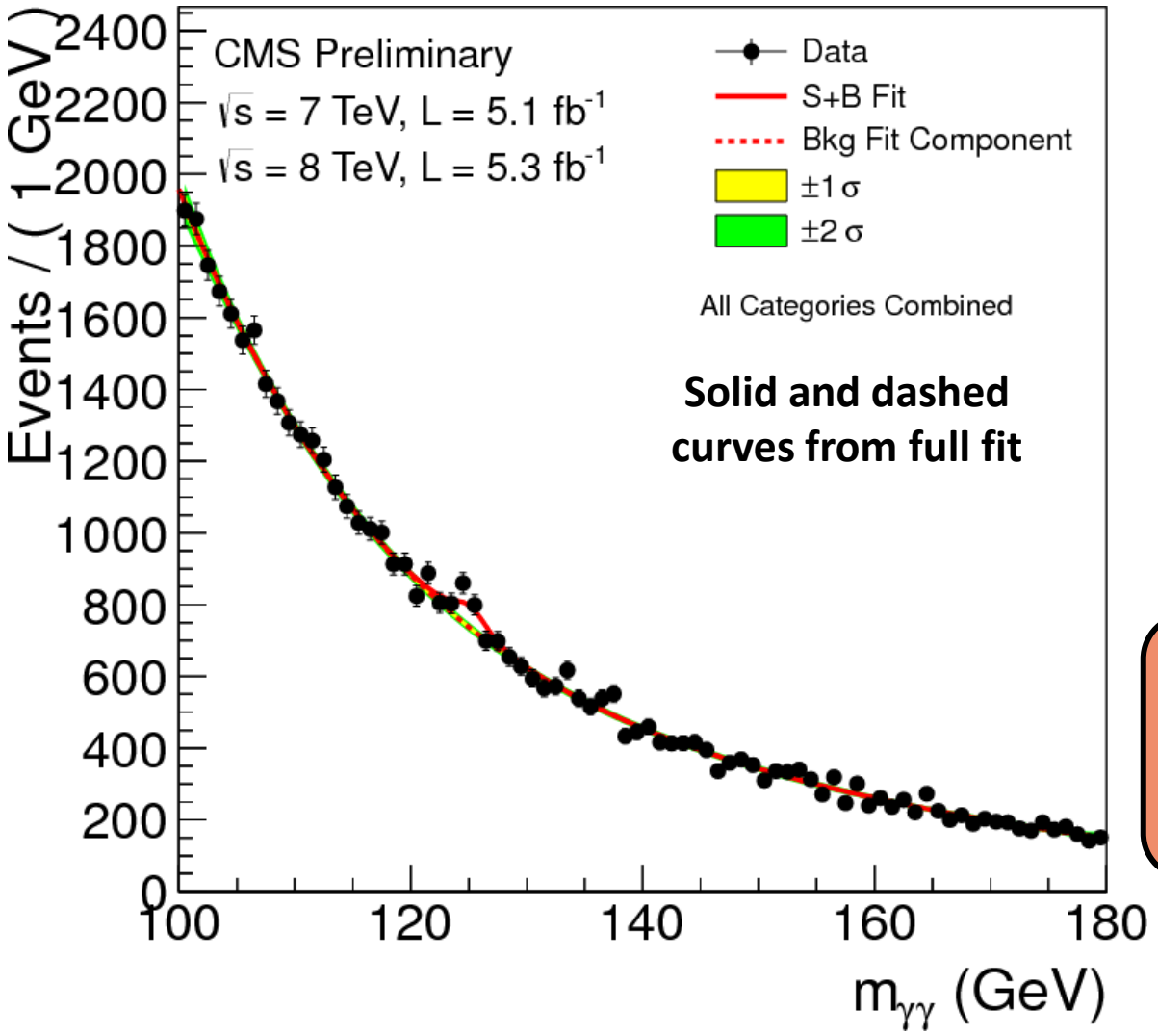








Combined Unweighted Mass Plot



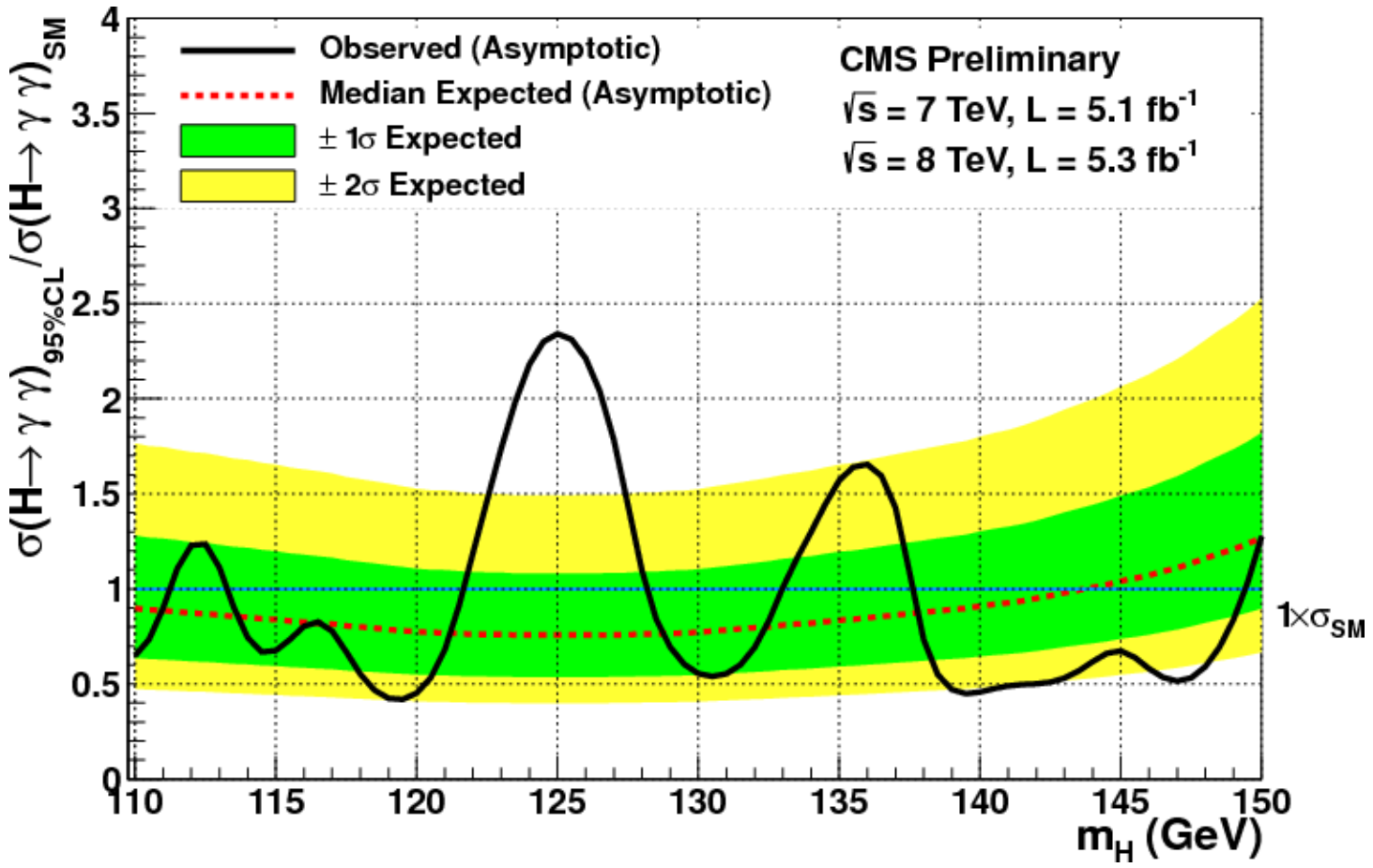
Data: unweighted sum of $m_{\gamma\gamma}$ for all 11 categories

Dashed: unweighed sum of background polynomials

Solid: unweighted sum of signal+background for all categories combined

Despite the reduced sensitivity from combining categories, evidence of an excess near 125 GeV is visible.

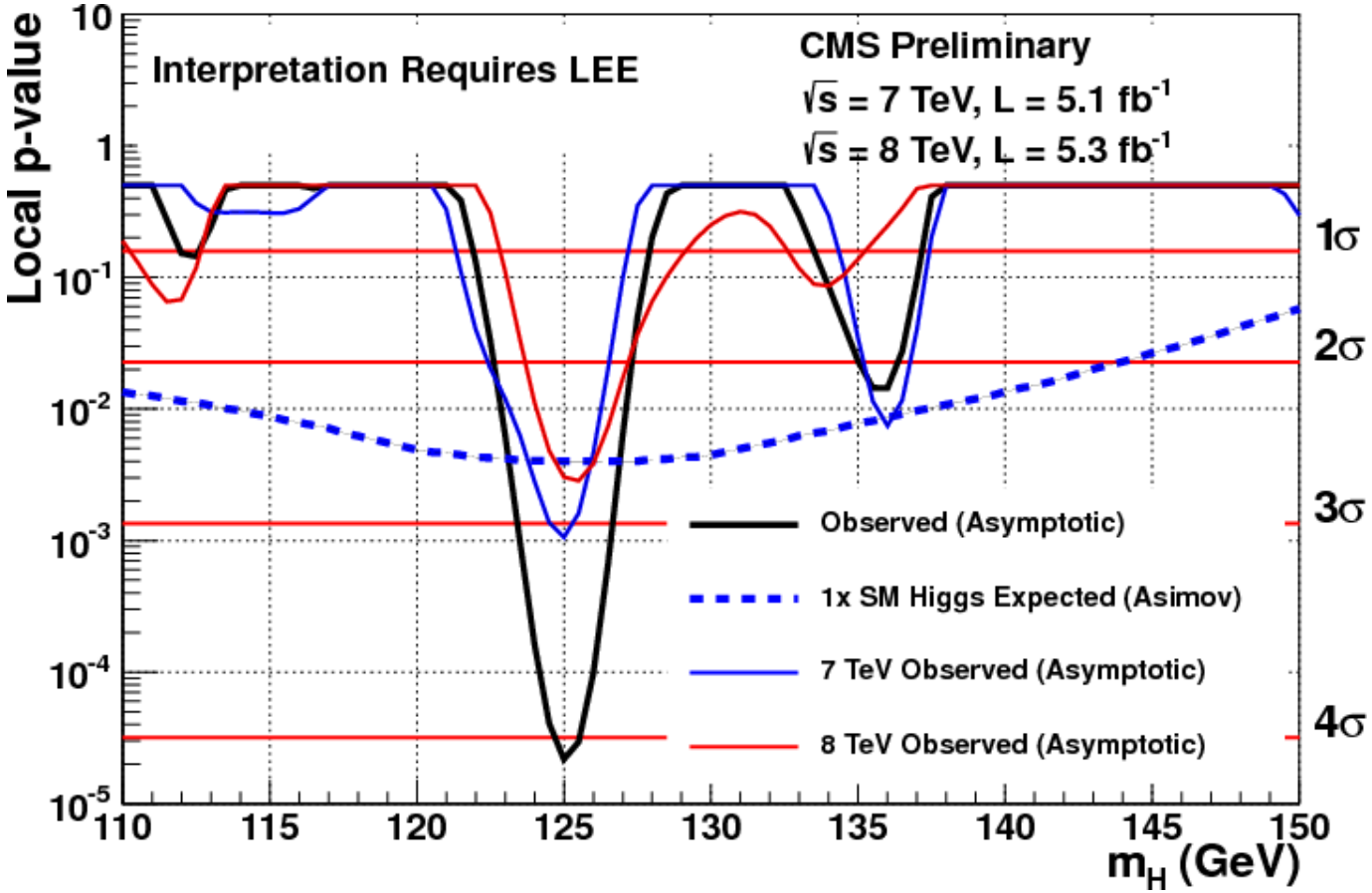
Exclusion Limits (95% CL)



Expected exclusion is below SM prediction between 110 and 144 GeV

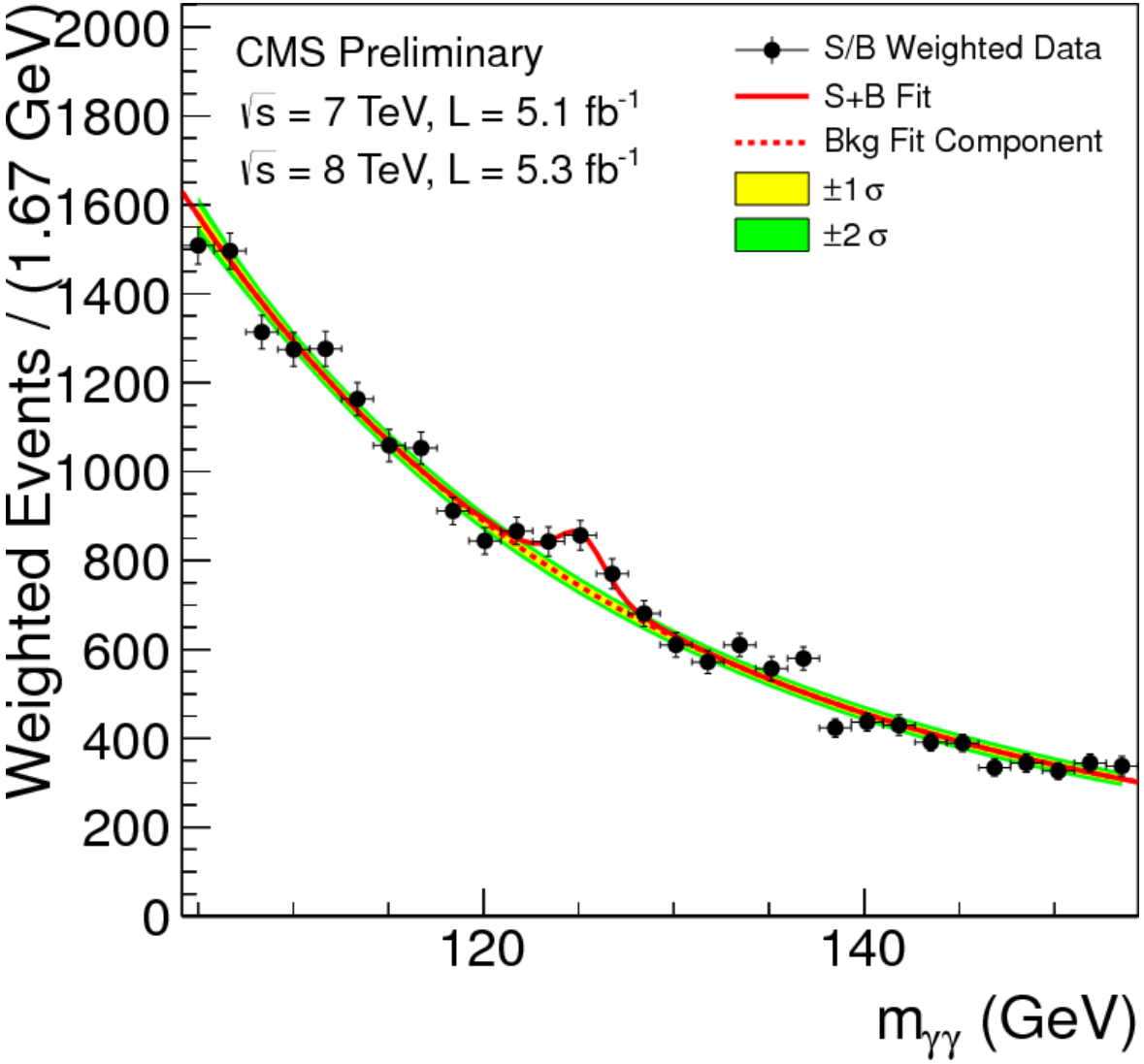
Two regions of excess: largest near 125 GeV, second largest near 136 GeV

p-values for H → γγ



- **Largest excess has a local (global) significance of 4.1σ (3.2σ)**
- **Excesses observed near 125 GeV in both 7 and 8 TeV data**
  - Excess near 136 GeV has local significance of ~2σ and is not seen in 8 TeV data

Weighted Mass Distribution

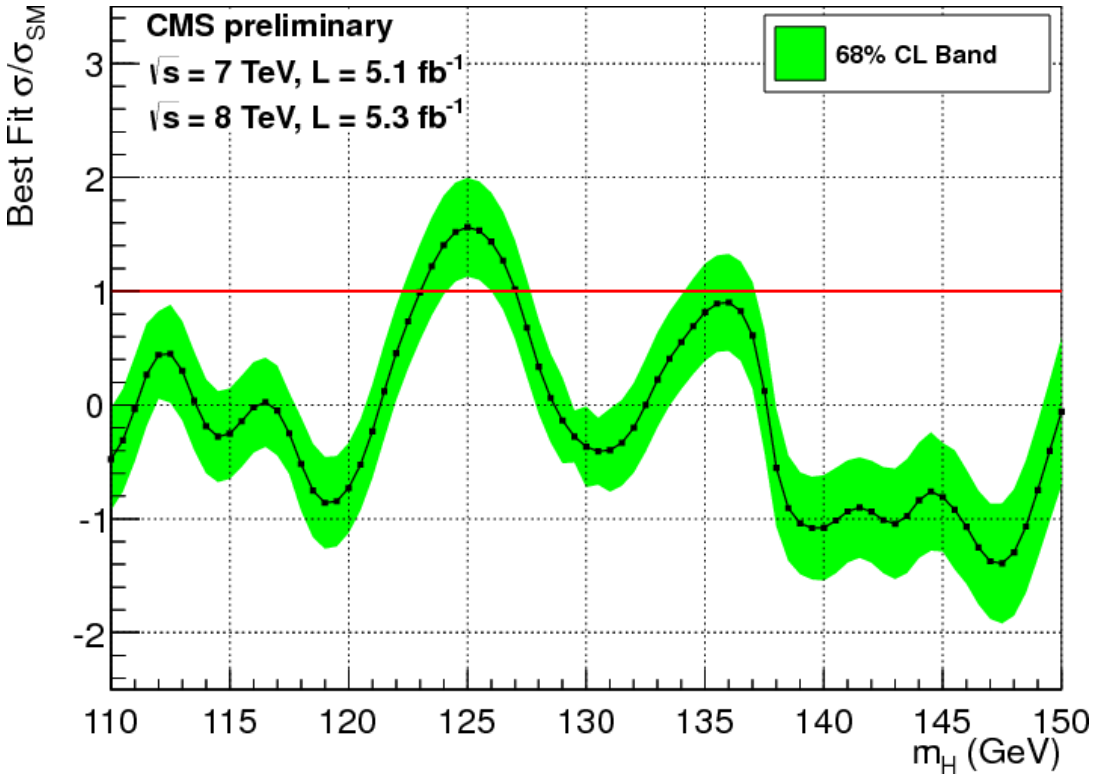


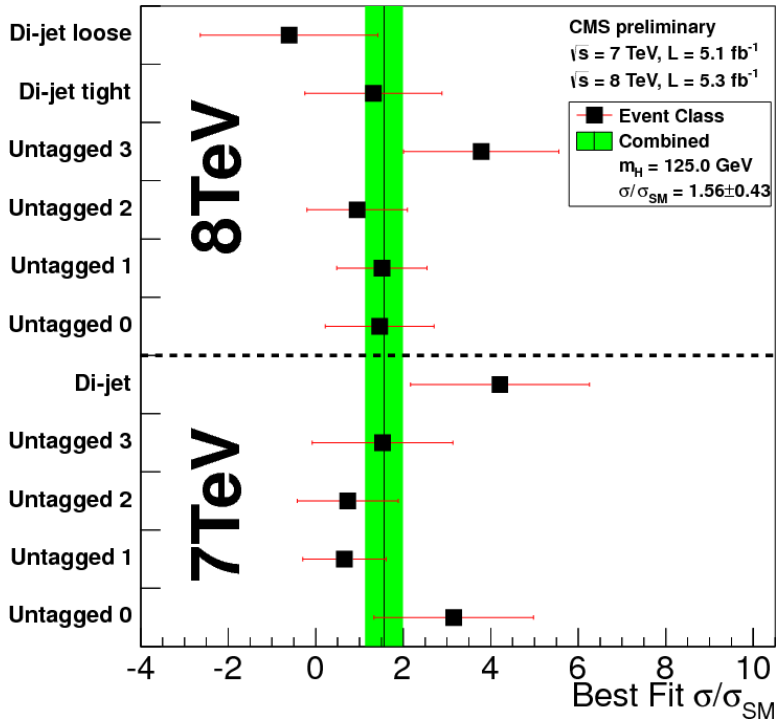
Sum of $m_{\gamma\gamma}$ distributions for all categories, weighted by S/B, where B is the integral of the bkg model over a constant signal fraction.

Not used in the analysis

A simple way to visualize what the full CLs machinery sees (robust against weight factor, signal mass, etc)

Signal Strength in H → γγ





- **Combined best fit σ/σ_{SM} at 125 GeV: 1.56 ± 0.43**
- Consistent with a SM Higgs at this mass, and all categories are consistent with the combined result

What do we have so far?

Evidence in CMS for a previously unobserved particle with a mass of roughly 125 GeV and decaying to photons

Any particle decaying in a diphoton channel cannot be a fermion, so **if** this is a new particle, **it must be a boson**

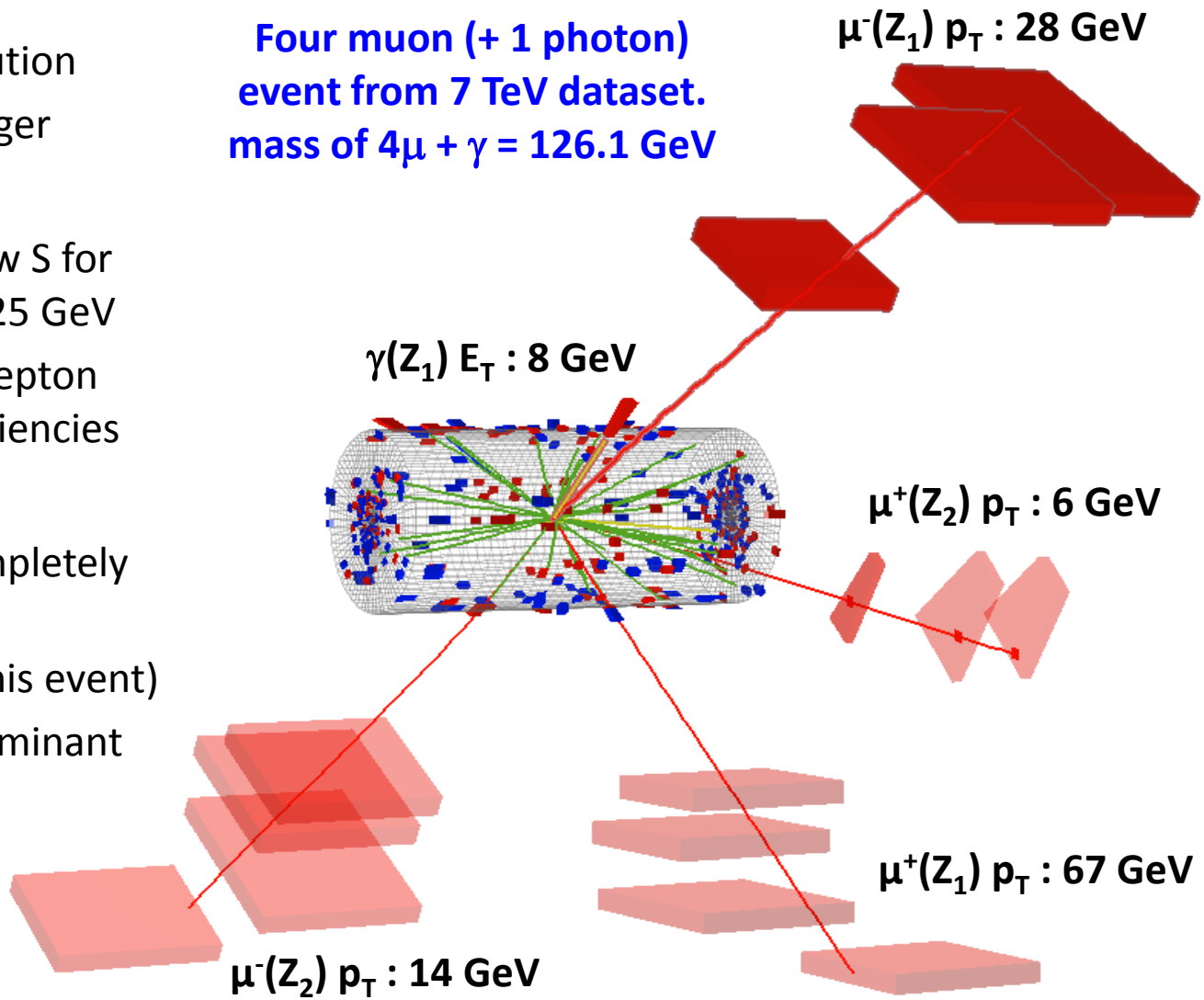
We have two independent experiments seeing consistent excesses in the same final state, at the same strength, and at roughly the same mass

Conclusion: the LHC has observed a new boson with a mass of roughly 125 GeV

Can we say more?

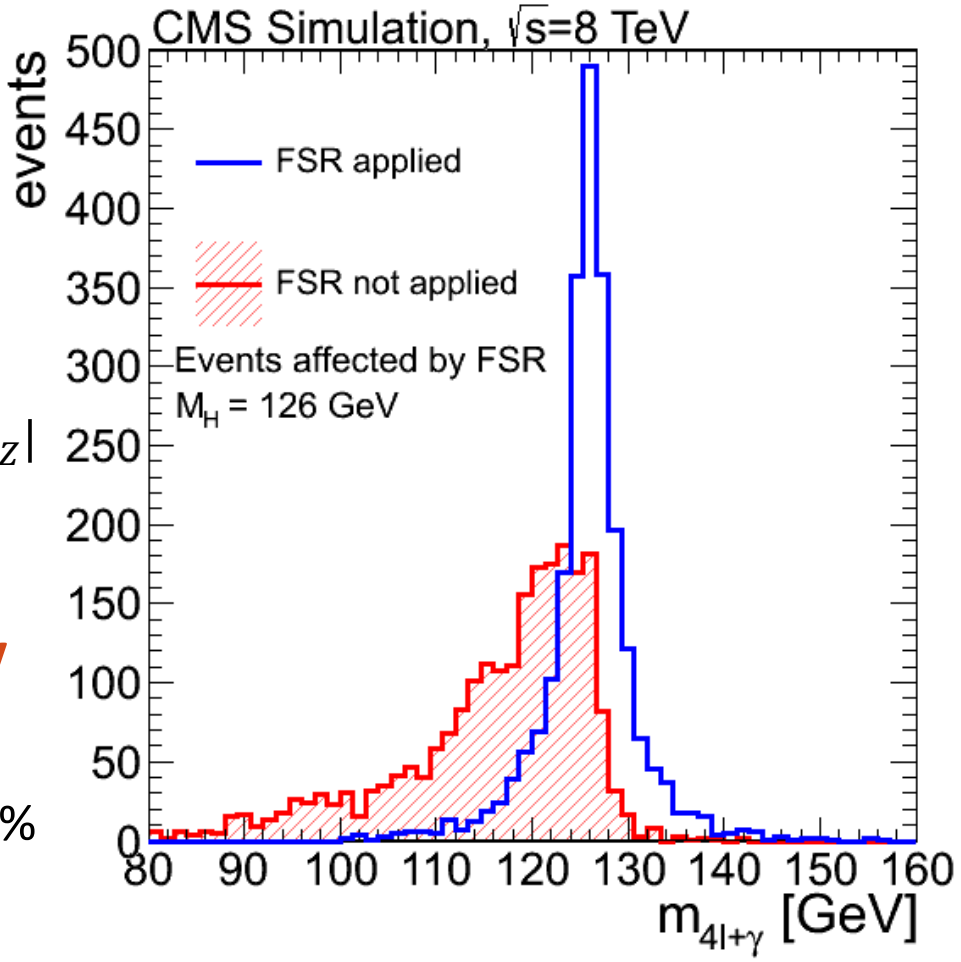
Overview of $H \rightarrow ZZ^* \rightarrow 4\ell$ (ℓ=e,μ)

- **Advantages**
  - Very clean channel
  - Excellent mass resolution
  - Readily available trigger
- **Challenges**
  - High S/B, but very low S for Higgs masses near 125 GeV
  - Must maintain high lepton trigger and reco efficiencies
- **Changes since 2011**
  - Lepton selection completely reoptimized (blind)
  - FSR recovery (as in this event)
  - New kinematic discriminant



FSR Recovery

- **Technique**
  - Find photons near leptons before isolation is applied
  - $E_T > 2$ GeV, $|\eta| < 2.4$
  - Associate photon to lepton if:
    - $M(ll+\gamma) < 100$GeV
    - $|M(ll+\gamma) - M_Z| < |M(ll) - M_Z|$
  - Photon is then removed from lepton isolation calculation
- **Performance for M_H = 126 GeV**
  - Only 6% of events are affected
  - Average purity of association ~80%
  - Efficiency gain ~2%

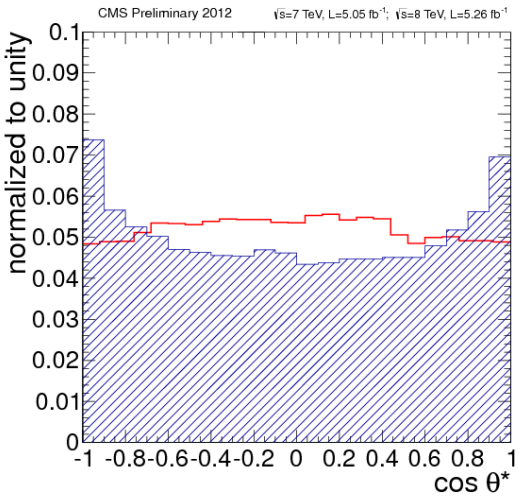


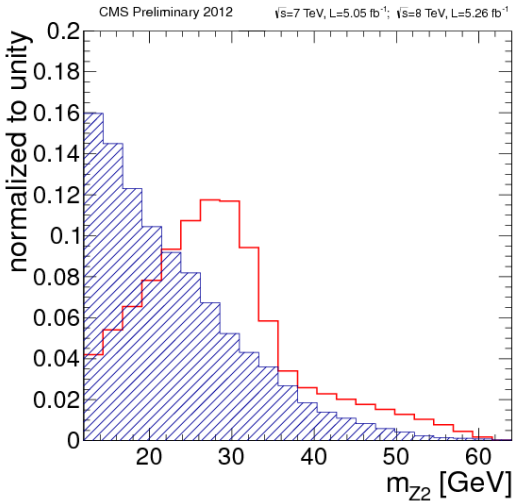
New Discriminant: MELA

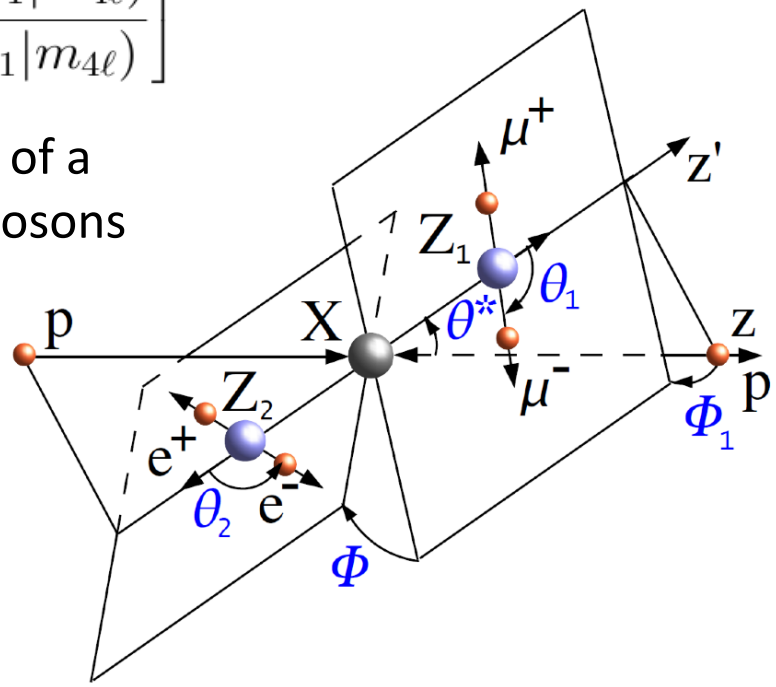
- **Matrix Element Likelihood Analysis**

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

  - Exploit known kinematics and topology of a scalar X decaying to two heavy vector bosons that then decay to two charged leptons

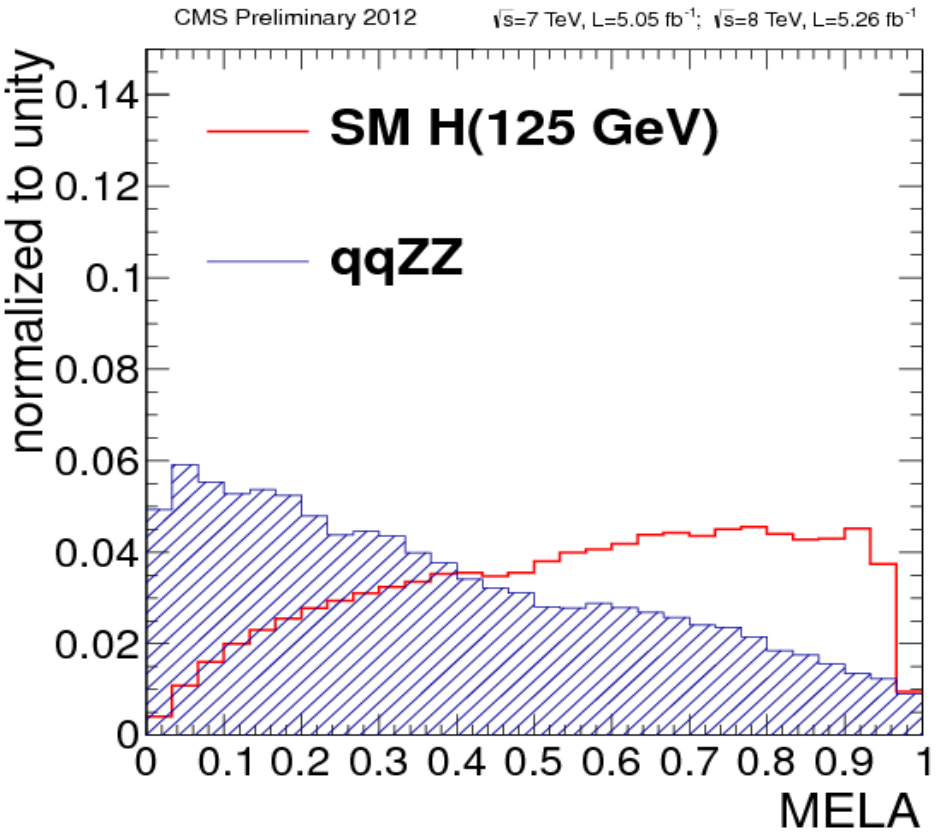




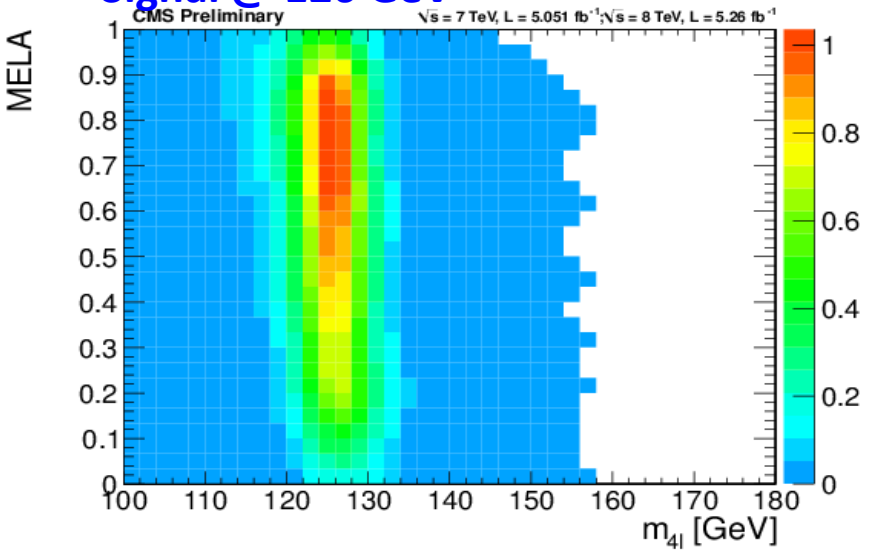


Significant gain in S/B, this channel is now the most sensitive at 125 GeV

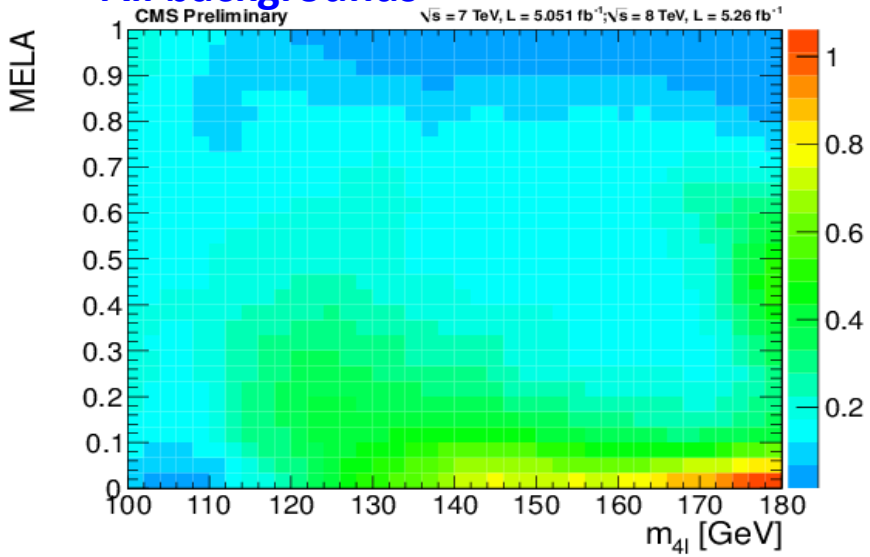
Expected MELA Performance



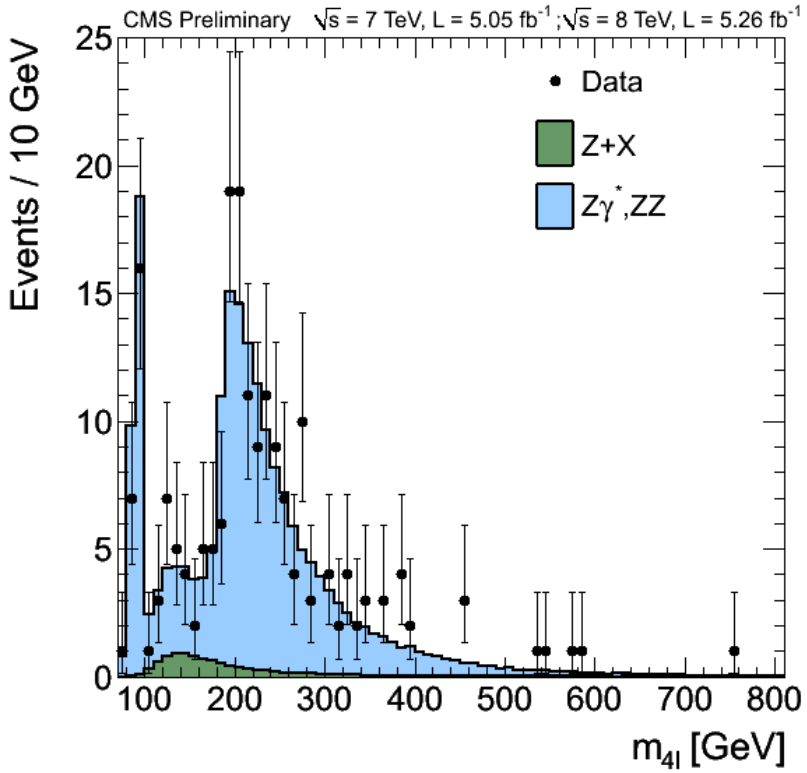
Signal @ 126 GeV



All backgrounds



Mass Distribution: 70-800 GeV



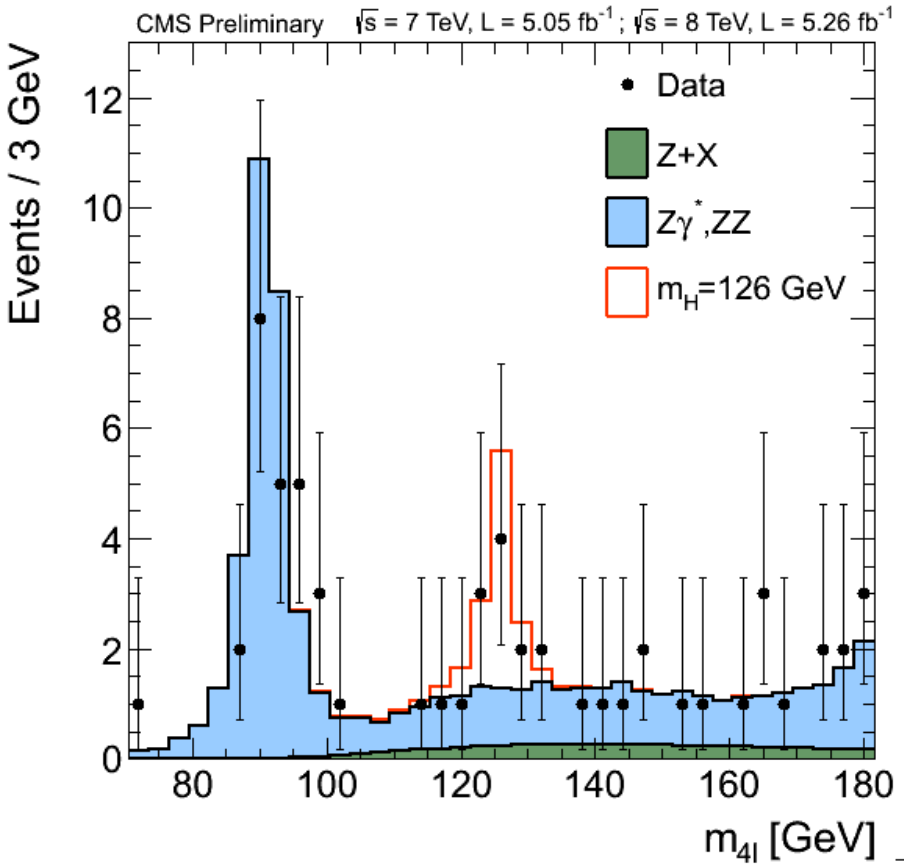
Channel	4e	4μ	2e2μ	4ℓ
ZZ background	29.3 ± 3.4	49.0 ± 5.1	75.5 ± 8.0	153.7 ± 10.1
Z+X	$3.0^{+2.7}_{-1.9}$	$2.2^{+1.6}_{-1.3}$	$5.0^{+4.0}_{-3.0}$	$10.2^{+5.0}_{-3.8}$
All backgrounds	$32.3^{+4.4}_{-3.9}$	$51.2^{+5.3}_{-5.3}$	$80.5^{+9.0}_{-8.6}$	$163.9^{+11.3}_{-10.8}$
$m_H = 200$ GeV	8.3 ± 2.0	13.3 ± 2.7	21.6 ± 4.5	43.2 ± 5.6
$m_H = 350$ GeV	4.8 ± 1.2	7.5 ± 1.6	12.7 ± 2.9	24.9 ± 3.5
$m_H = 500$ GeV	1.7 ± 0.8	2.6 ± 1.2	4.4 ± 2.0	8.7 ± 2.4
Observed	32	47	93	172

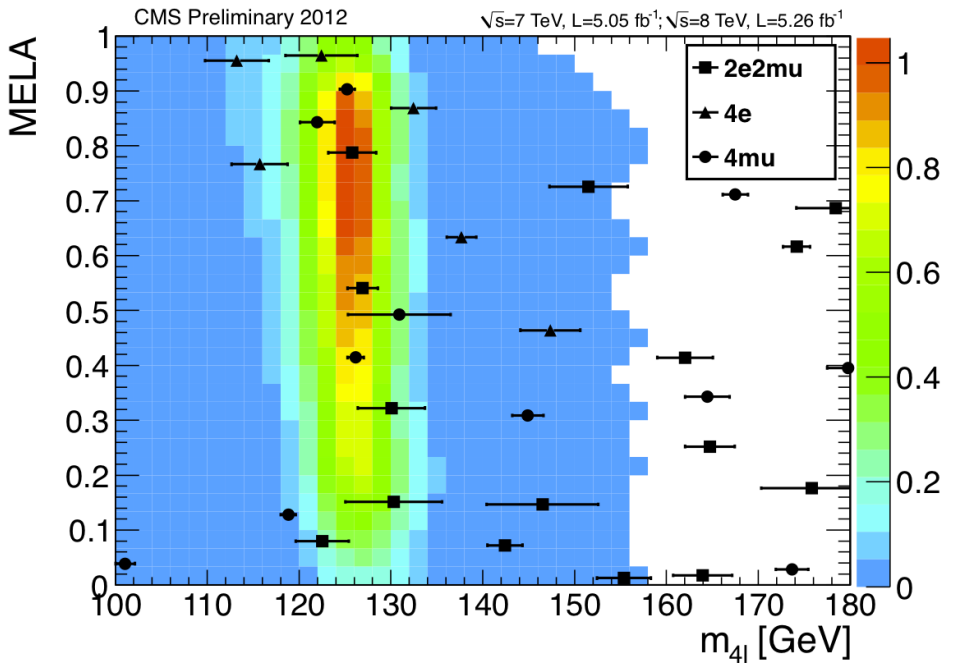
Bin size is several times detector resolution, signal is washed out

Very good agreement with predicted backgrounds across the entire mass range, including Z → 4l peak

Expect 164 ± 11 across all channels, see 172.

Zoomed Mass: 70 - 180 GeV

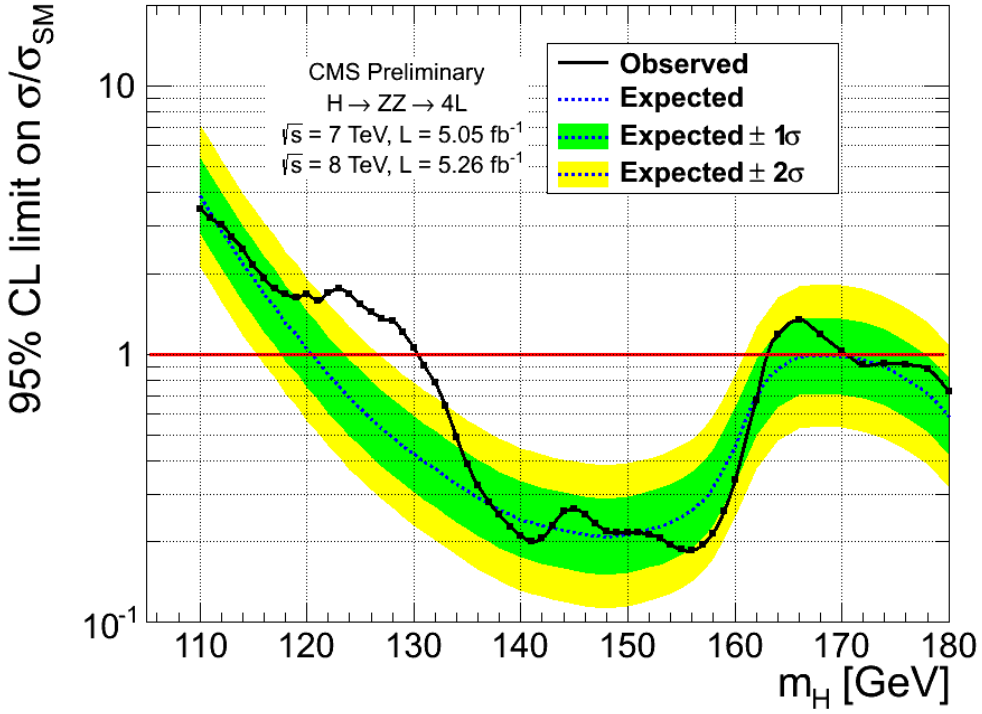


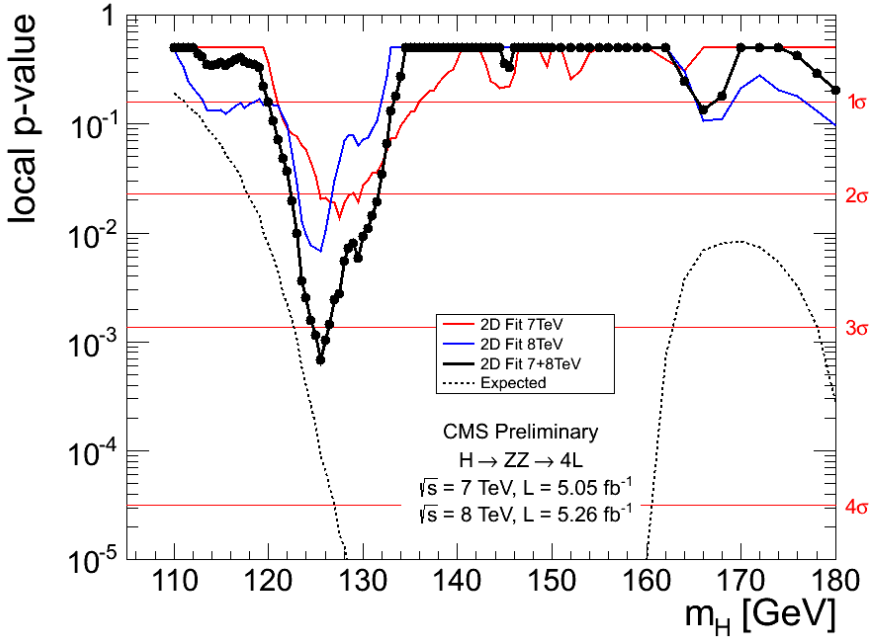


An excess of events is observed in the region around 126 GeV, MELA plot consistent with expected S+B

Channel	4e	4μ	2e2μ	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.5 ± 1.0
Z+X	$1.2^{+1.1}_{-0.8}$	$0.9^{+0.7}_{-0.6}$	$2.3^{+1.8}_{-1.4}$	$4.4^{+2.2}_{-1.7}$
All backgrounds	$3.9^{+1.1}_{-0.8}$	$6.6^{+0.9}_{-0.8}$	$9.5^{+2.0}_{-1.6}$	$19.9^{+2.4}_{-2.0}$
$m_H = 120$ GeV	0.8 ± 0.2	1.6 ± 0.3	1.9 ± 0.5	4.4 ± 0.6
$m_H = 126$ GeV	1.5 ± 0.5	3.0 ± 0.6	3.8 ± 0.9	8.3 ± 1.2
$m_H = 130$ GeV	2.1 ± 0.7	4.1 ± 0.8	5.4 ± 1.3	11.6 ± 1.6
Observed	6	6	9	21

Exclusion limits and p-value plot



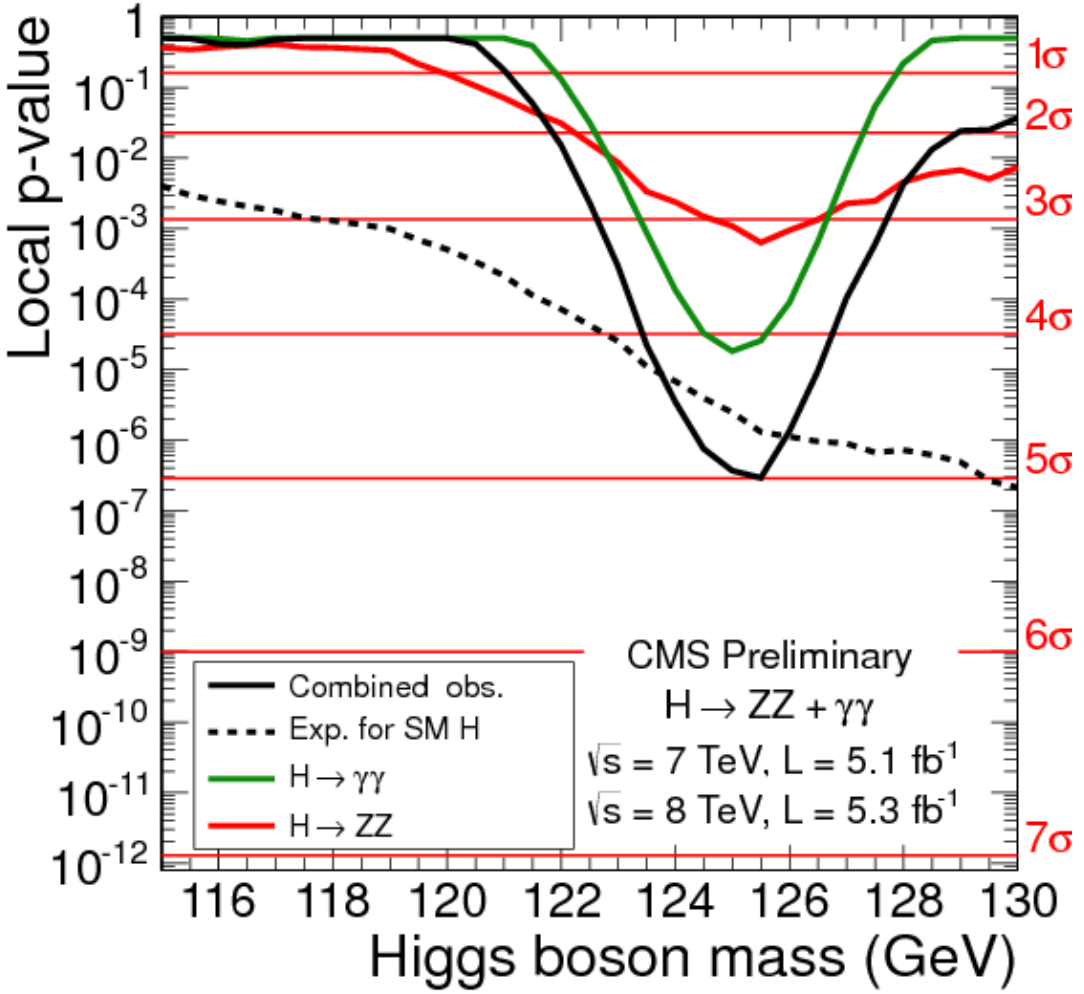


Expected exclusion: 121 - 555 GeV

Observed exclusion: 131 - 162 GeV, 172 - 530 GeV

Largest excess is at 125.5 GeV, has a significance of 3.2σ, and a signal strength of σ/σ_{SM} = 0.7

Combined Results for $\gamma\gamma$ + ZZ*



Channels with best mass resolution, and highest sensitivity at 125 GeV

- $\gamma\gamma$: 4.1σ significance
- ZZ*: 3.2σ significance
- **both for mass near 125 GeV**

Combined observed (expected) local significance: 5.0σ (4.7σ)

Confirming evidence in another VV channel

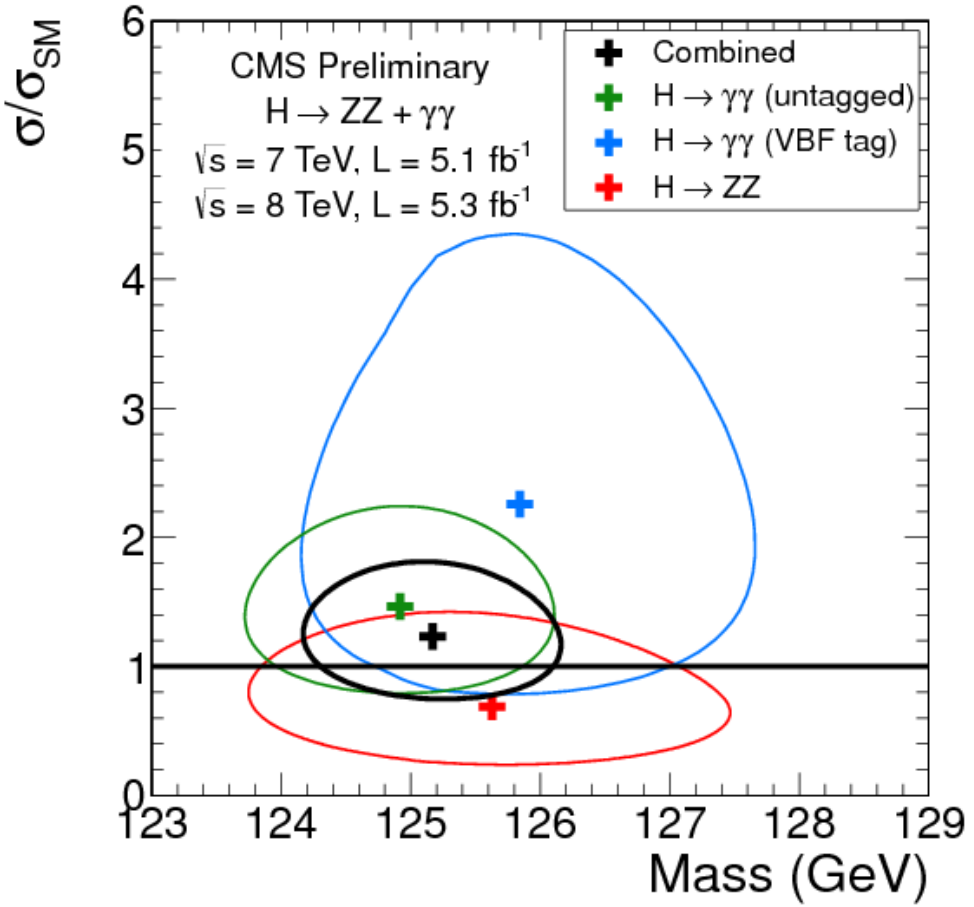
Combined Mass from $\gamma\gamma$ and ZZ*

Likelihood scan of the observed mass in the various categories of $\gamma\gamma$ and ZZ

Relative signal strengths are allowed to vary in order to reduce potential bias and model dependence

Stat unc. in individual channels not highly dependent on signal strength

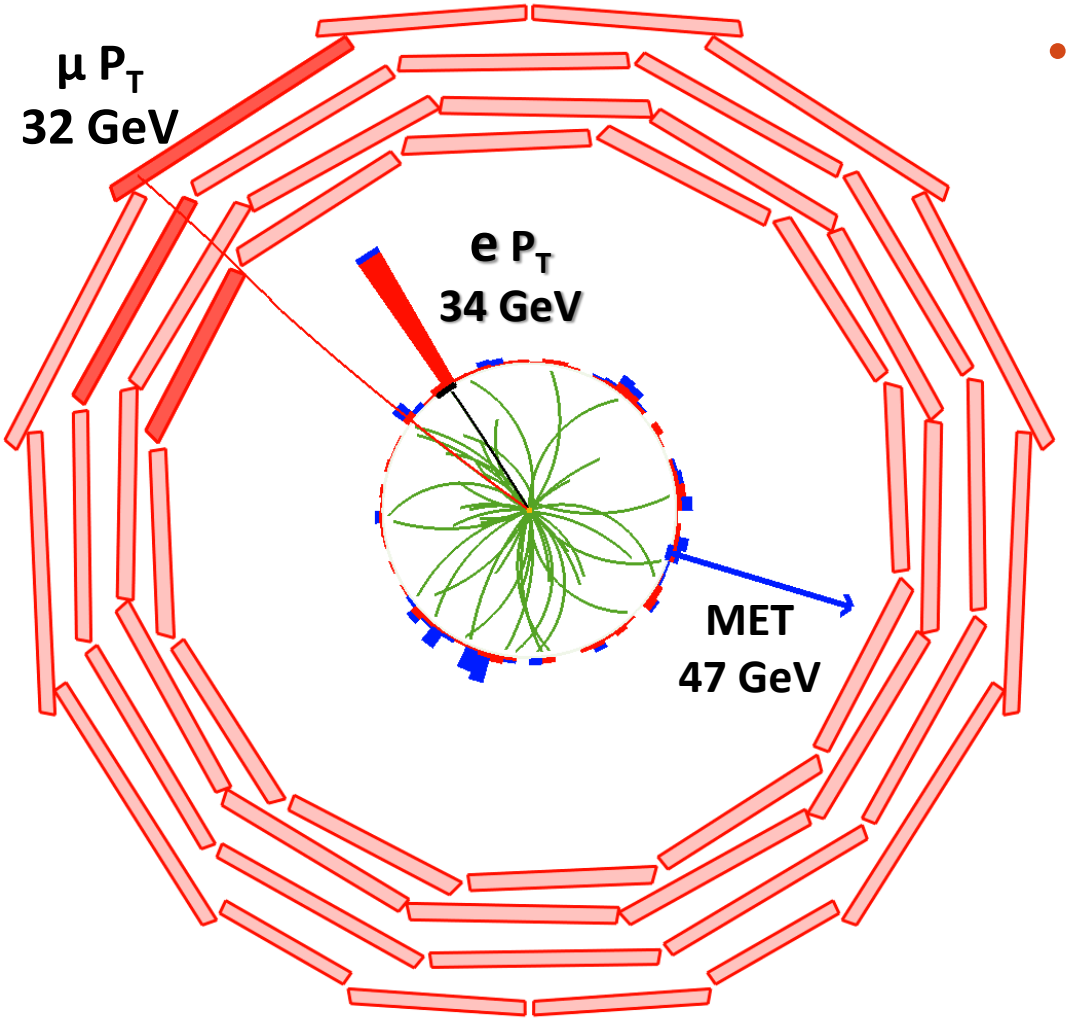
Full and conservative estimate of systematic uncertainties (± 0.5 GeV)



$$M = 125.3 \pm 0.4\,(\text{stat}) \pm 0.5\,(\text{syst})$$

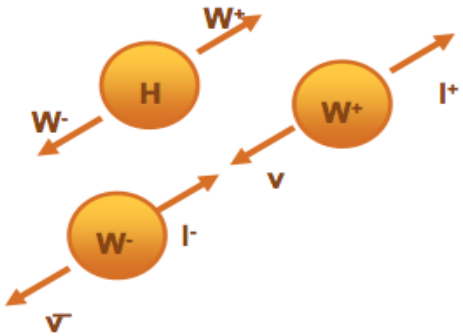
High Sensitivity, Low Resolution

$H \rightarrow WW \rightarrow 2\ell 2\nu$



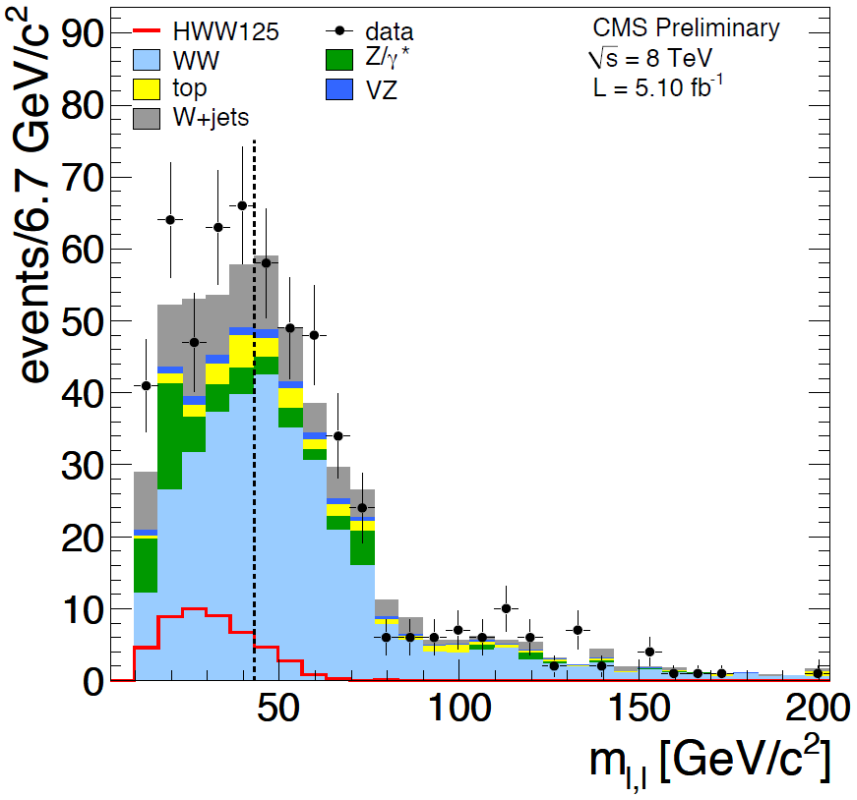
- **364kg Gorilla**
  - 2nd largest σ x BF
  - Charged leptons for trigger
  - Controllable backgrounds
  - Kinematic handles
- **Sensitivity: 115 – 600 GeV**

Spin-0 Higgs + V-A weak int. = small angle between ℓ's, and ν's

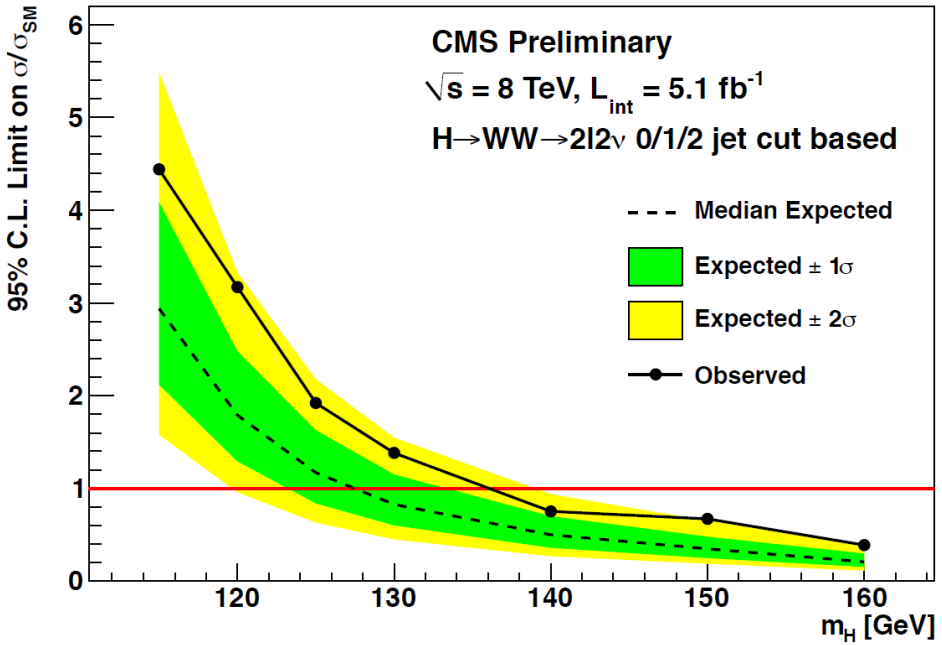


Only real drawback is no sharp mass peak (20% resolution in M_T)

H → WW→2ℓ2ν: Results

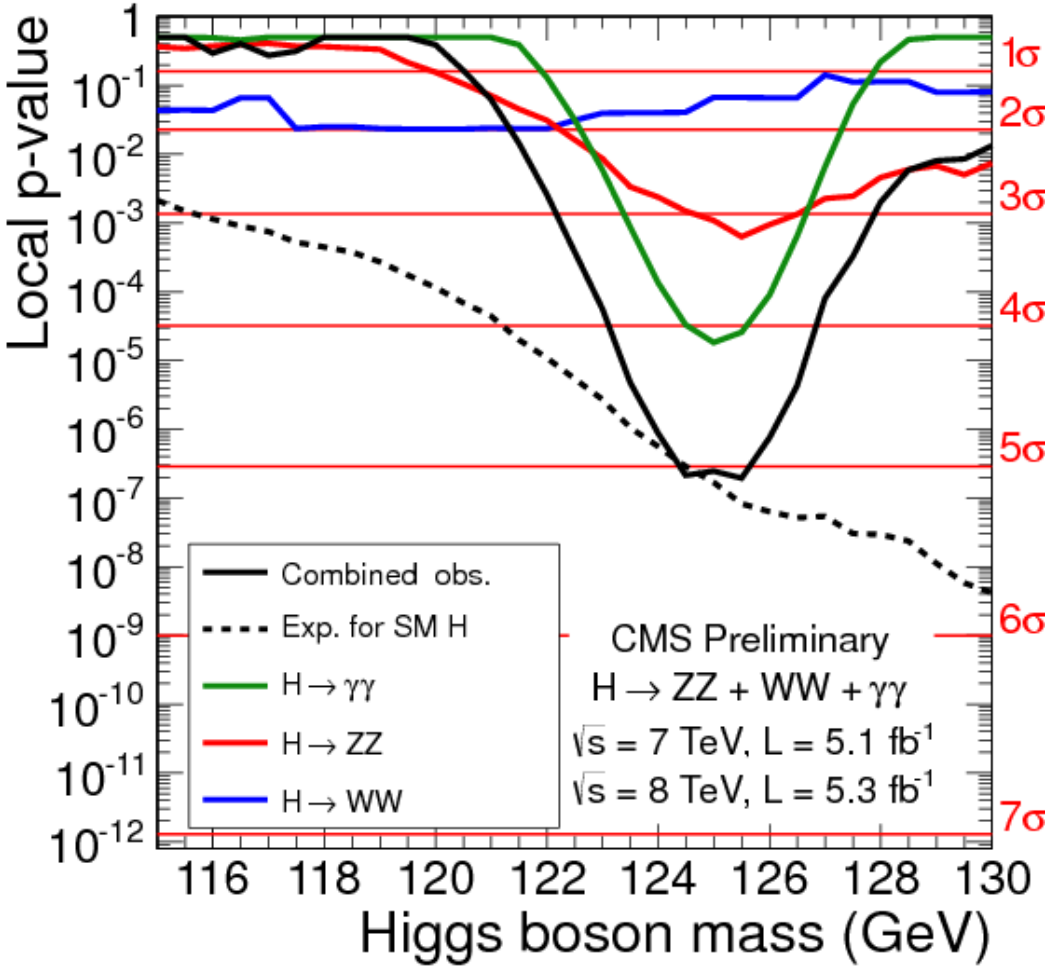


- **Analysis method:**
  - MVA shape analysis with 0/1 jet
    - **For 8 TeV, cut-based only**
  - Main bkgs obtained from data
  - Not much room left for improvement
  - For ICHEP update: no VH modes



- **Results (95% CL_S)**
  - Exp exclusion: 123-450 GeV
  - Obs exclusion: 129-520 GeV
  - Broad ~2σ excess at low mass

Combining all Boson Channels



Combining boson channels, local significance increases to 5.1σ

Expected significance for a SM Higgs boson is 5.2σ

AP photo

“As a layman, I think we have it. But as a scientist, I have to say, `What do we have?’” – R. Heuer

Where do we stand?

Observation in CMS, and independently in ATLAS, of a new boson with a mass of roughly 125 GeV decaying to vector bosons

It is certainly looking and walking like the SM Higgs boson. Does it also quack like the SM Higgs boson? Some questions:

Does it couple to fermions?

Is the width accounted for in the accessible channels?

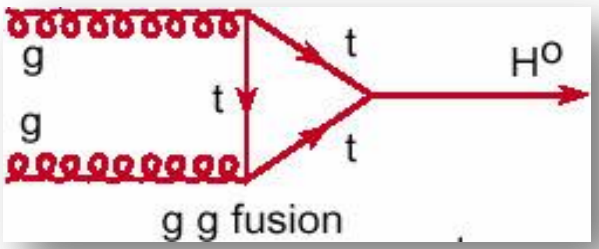
Are the relative signal strengths consistent with prediction?

We know it's a boson, we also know it is not spin 1. Is it spin 0?

If it is spin 0, is it a scalar or a pseudoscalar?

Does it Couple to Fermions?

Recall the gluon fusion diagram:



In the context of the SM Higgs boson phenomenology, we already have strong **indirect** evidence for a coupling to the top quark via the loop in the dominant production mechanism.

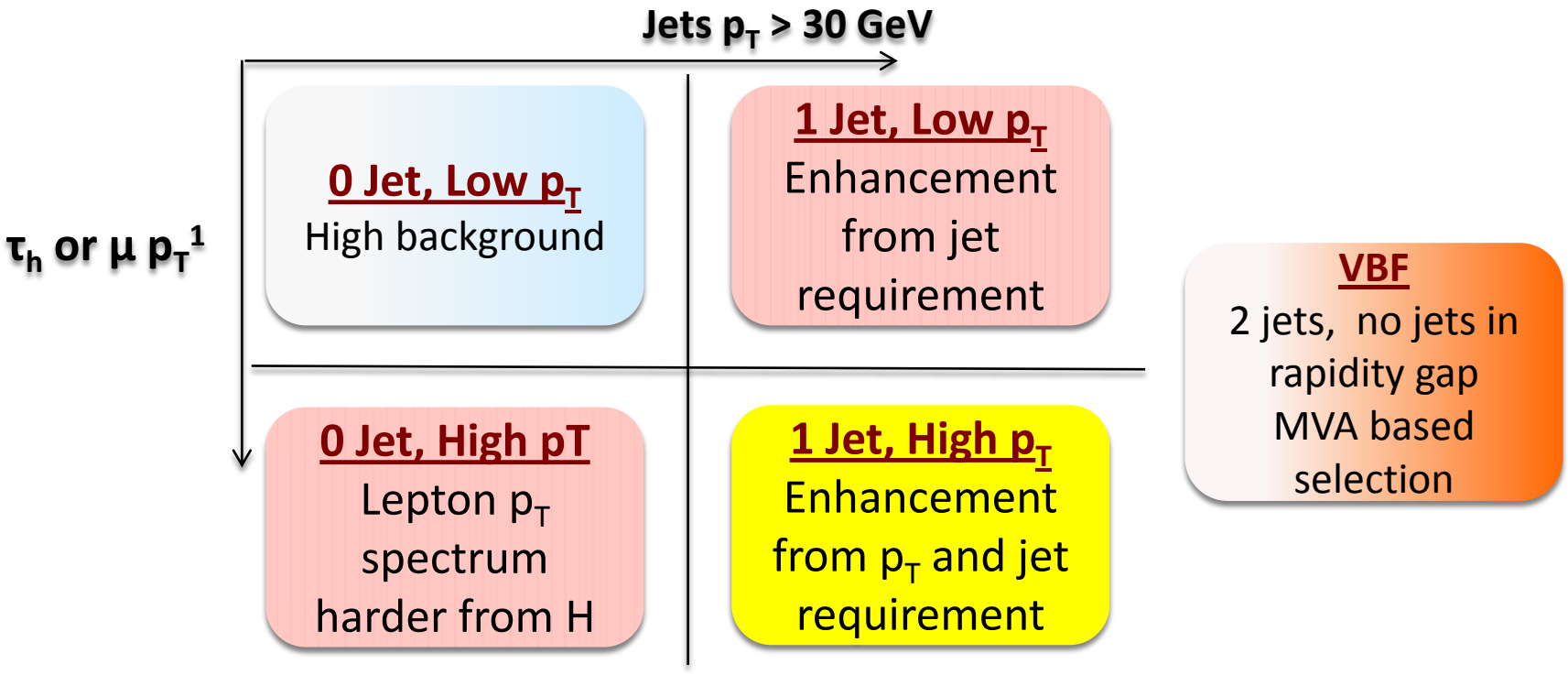
However, it could be that we are seeing a Higgs boson that helps break EWK symmetry, but gives mass to the W/Z and up-type fermions **only**, for example (I am keeping an open mind, theorists are very creative!).

"Seeing is believing": need to observe this new boson decaying in a fermion final state before we can definitively state that we have a candidate for a single SM-like Higgs boson that gives mass to all the fundamental particles.

Hunt for the Fermions

Overview of $H \rightarrow \tau\tau$

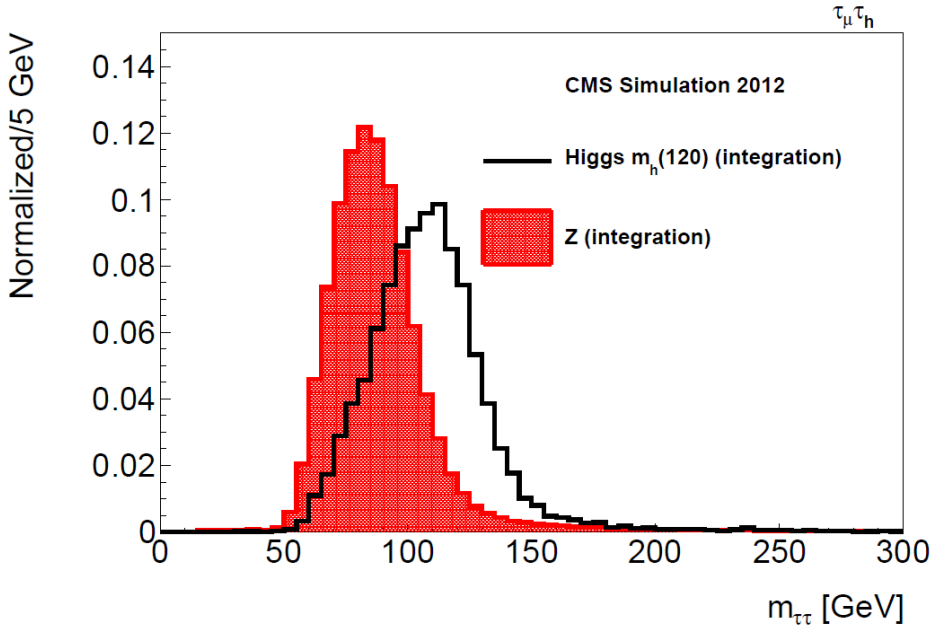
- Search performed in 4 tau-pair final states: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\mu\mu$
- Analysis divided into 5 categories: mass resolution, S/B
- All categories are fit simultaneously



Primary challenge: final state not fully reconstructed

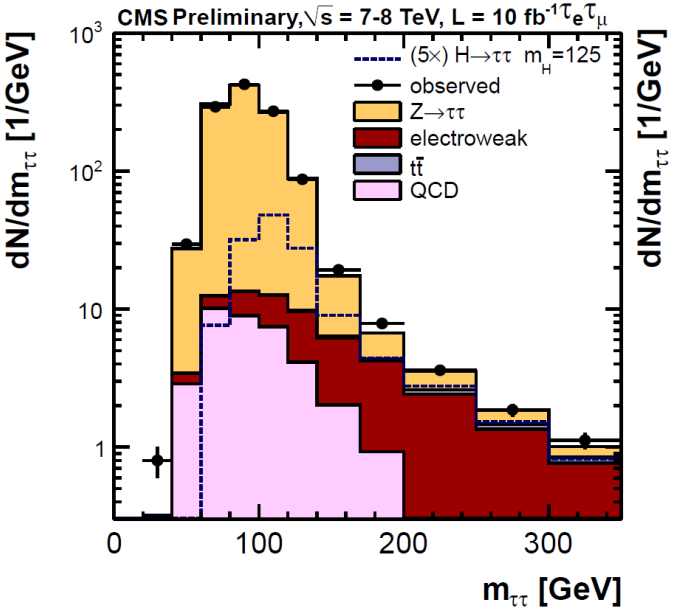
Mass Reconstruction

- **SVFit**
  - Event-by-event estimator of true m(ττ) distribution
    - Matrix Element used for τ→lνν
    - Phase-Space used for τ→π
    - Nuisance parameters are integrated out
- **Mass peaks at true value**
  - 20 % improved resolution with respect to 2011
  - Better separation between low-mass Higgs and Z



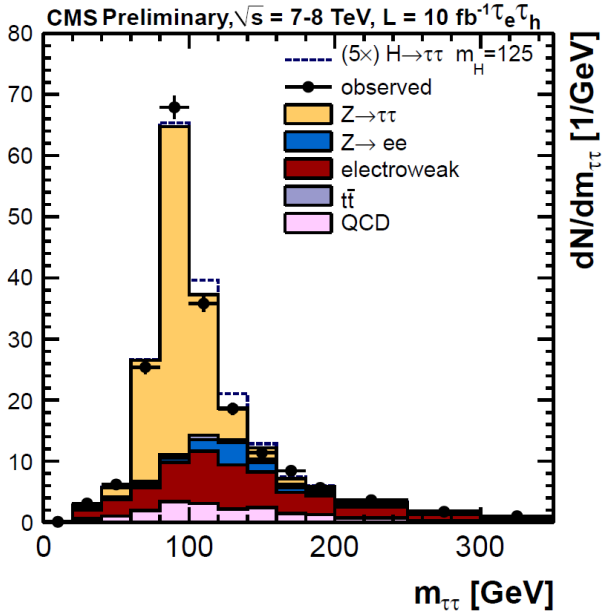
Mass Distributions

e-μ in 0-jet category



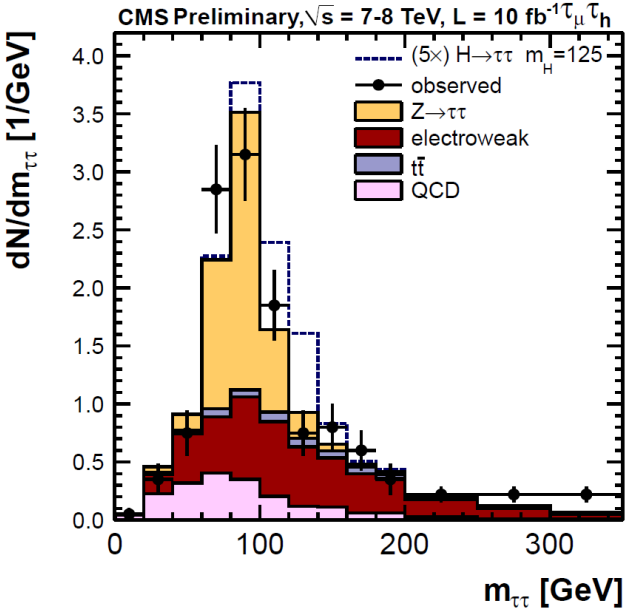
- Mostly gluon fusion
- Use high/low boost split
- Useful to constrain nuisance parameters

e-τ_h in 1-jet category



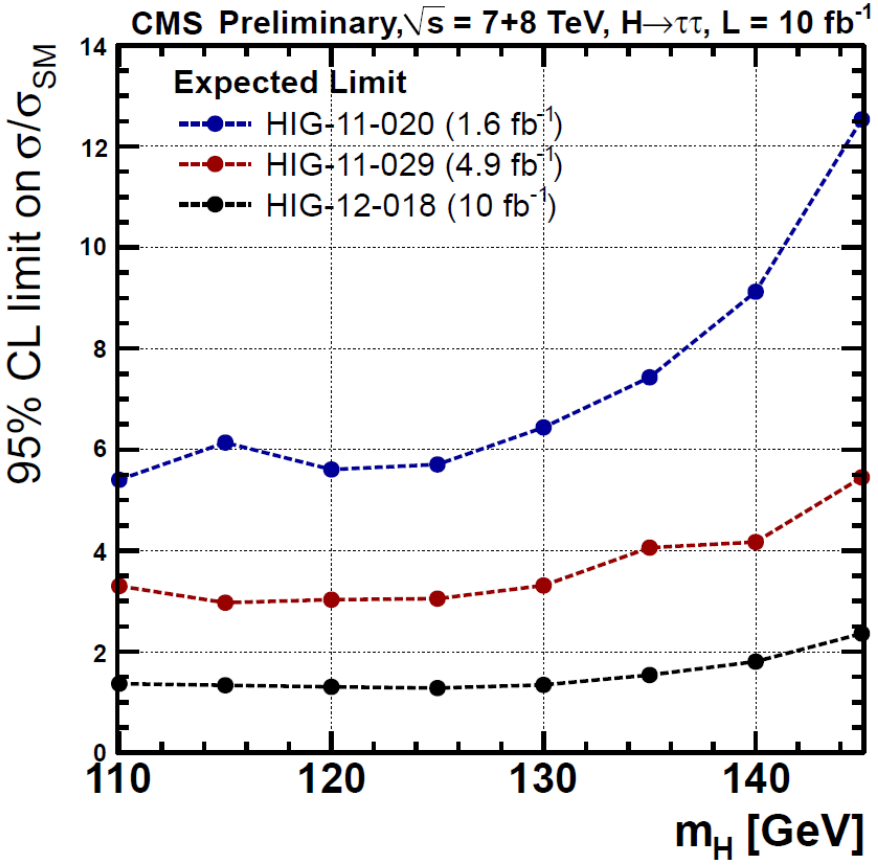
- Enhanced in gluon fusion
- Better mass resolution
- Use high/low boost split

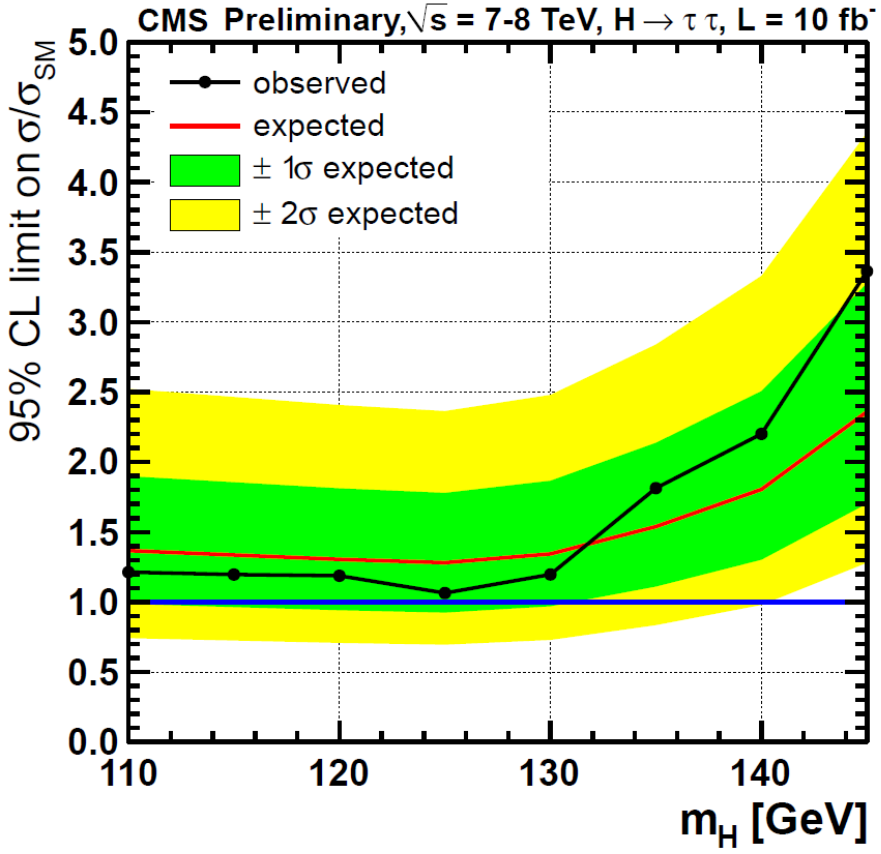
μ-τ_h in 2-jet category



- VBF category
- Highest S/B
- Best sensitivity < 130 GeV

Results for $H \rightarrow \tau\tau$





Sensitivity improved ~50% on per fb^{-1} basis
Total improvement ~2x relative to 7 TeV

Expected exclusion: 1.4 x SM @ 125 GeV

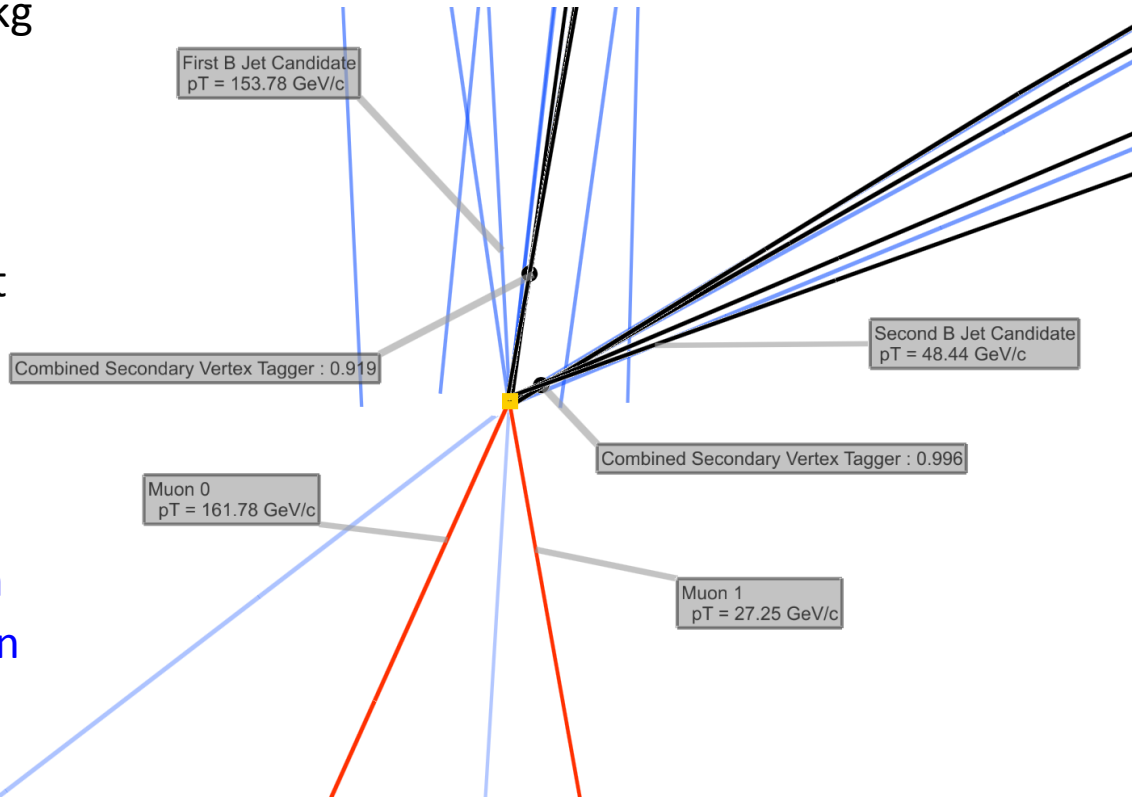
Observed exclusion: 1.06 x SM @ 125 GeV

Overview of $H \to b\bar{b}$

- **Critical puzzle piece**
  - soaks up > 50% of width @ 125
  - drives Tevatron excess at low mass
- **Most sensitive in VH channel**
  - V kills QCD and provides trigger
  - p_T spectrum is harder than bkg
  - 3 topologies (5 channels):
    - $Z\ell\ell$, $Z\nu\nu$, $W\ell\nu$ [ℓ = e, μ]
- **Improvements**
  - shape analysis on BDT output
  - energy regression
  - split into high/low pT

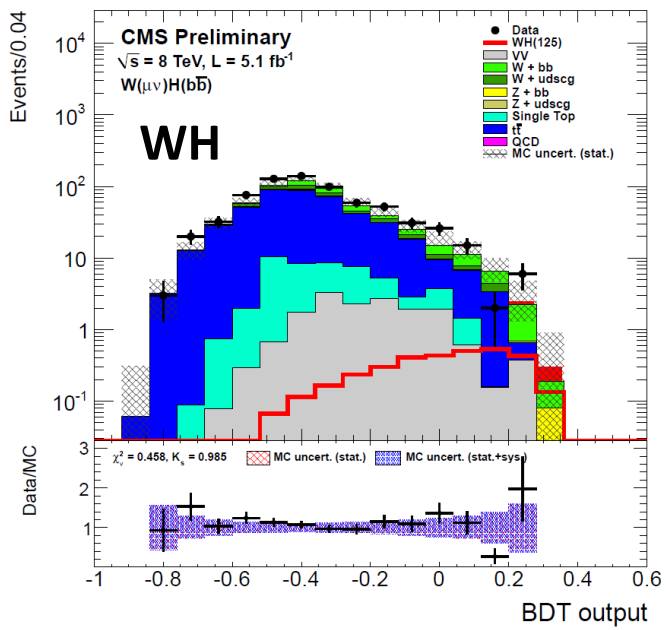
Look for boosted di-bjet system recoiling from a boosted W or Z

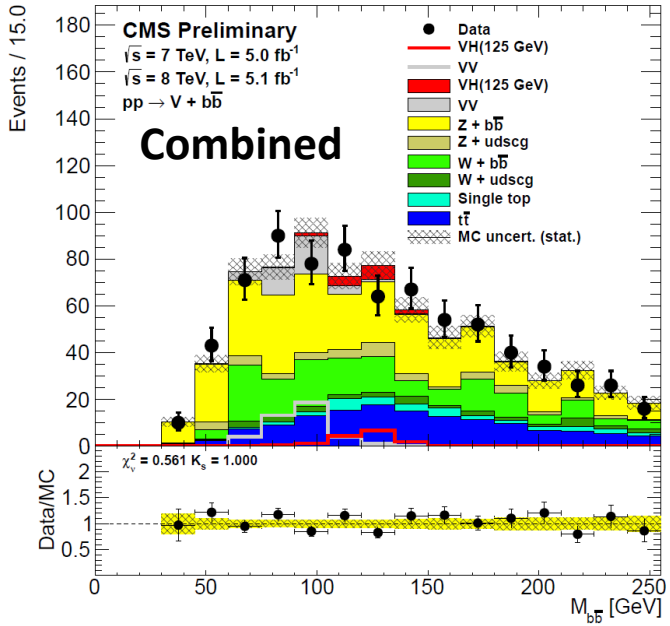
Candidate $pp \to Z(\mu\mu)H(bb)$ event



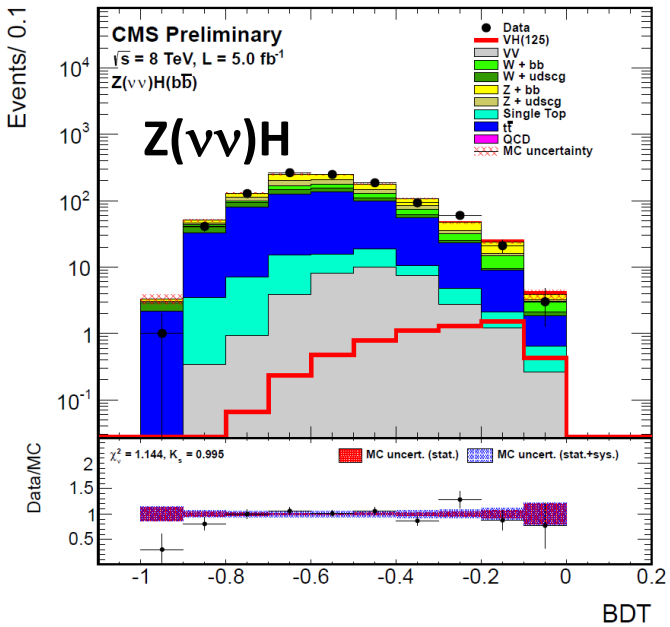
CMS also has a first set of exclusion limits looking at $t\bar{t}H(b\bar{b})$ production

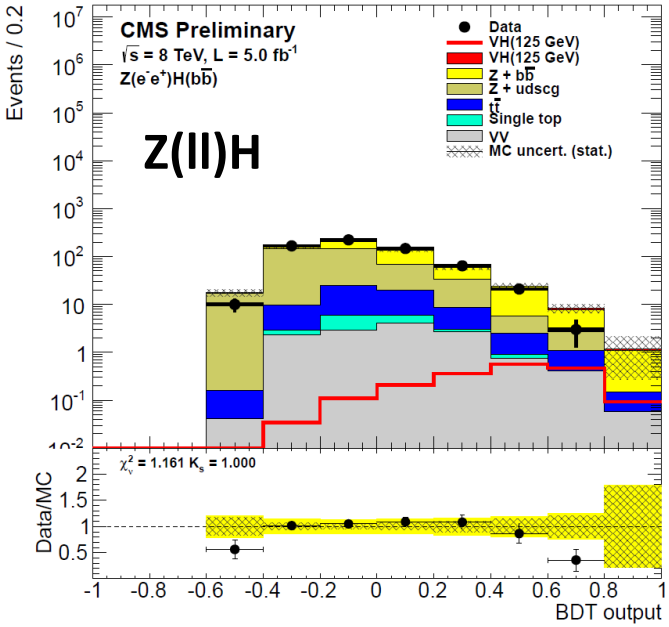
BDT and M_{bb} Distributions





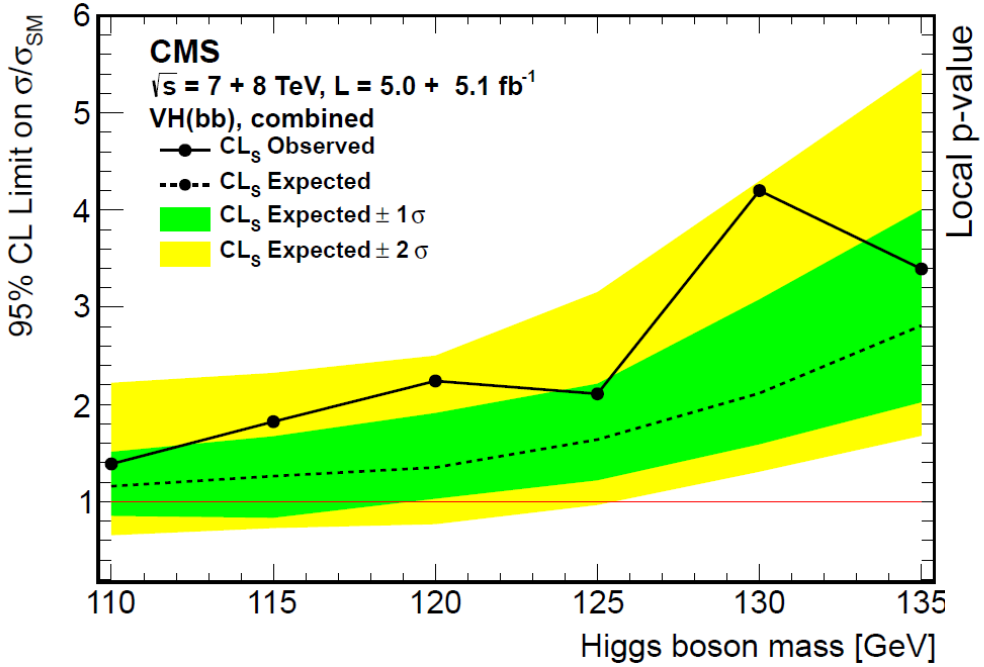
Not yet sensitive to VV+VH peak, but getting there

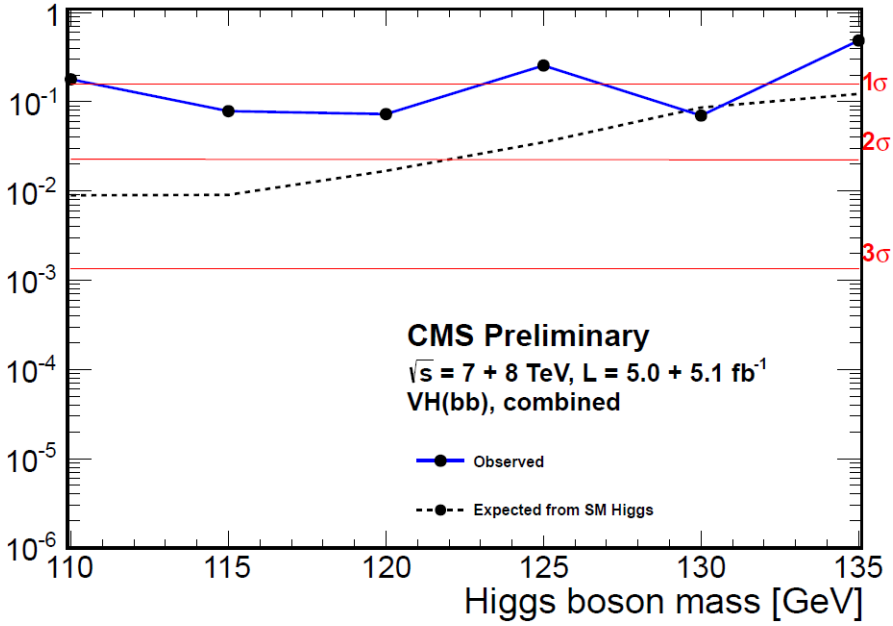




All plots are from high pT bins (highest S/B)

Results for $H \to b\bar{b}$



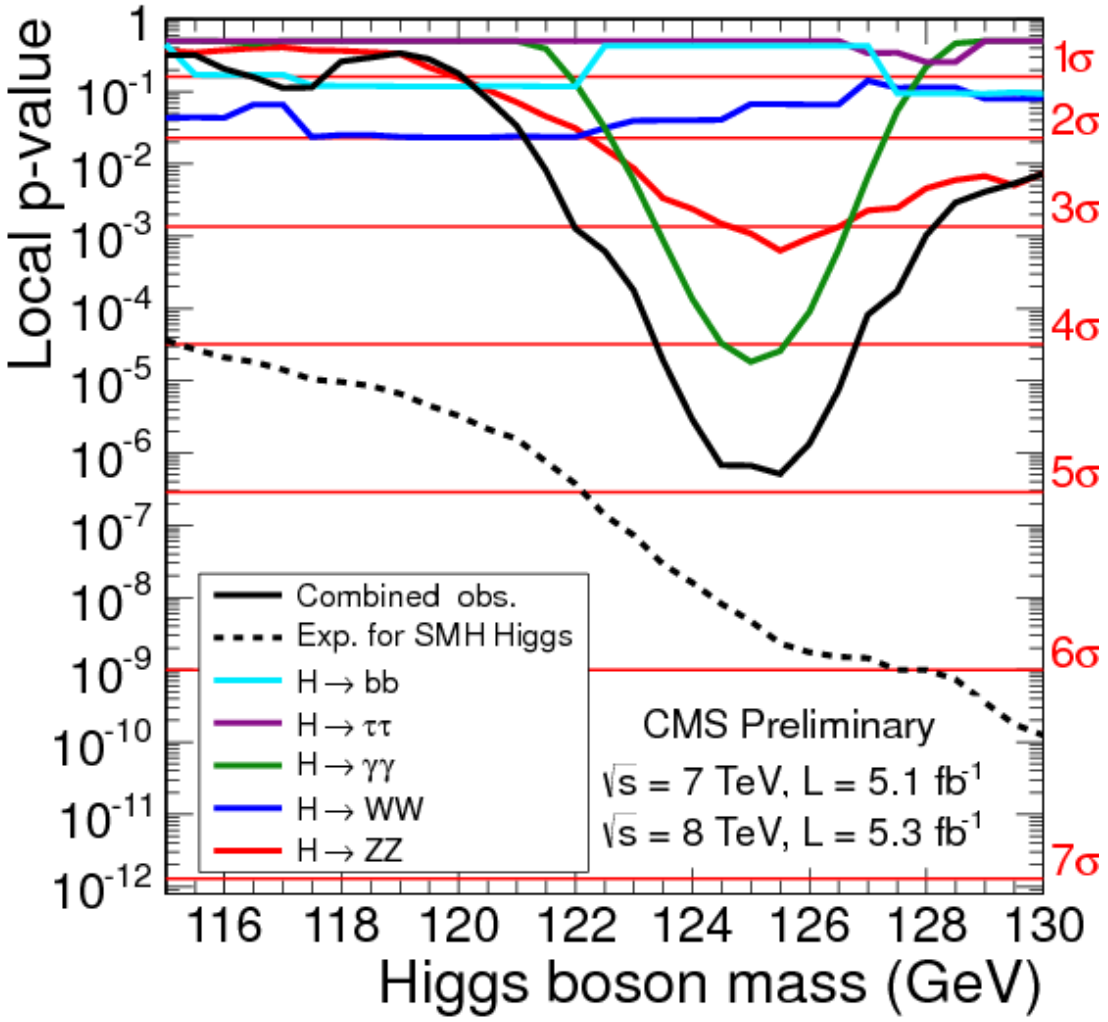


- **Results of BDT shape analysis**
  - 50% improvement in sensitivity on a per fb^{-1} basis
  - **exclude 1.6xSM @ 125 GeV**
  - Sensitivity to SM Higgs @ $25fb^{-1}$

Largest excess is ~1.5σ at 130 GeV

m_H(GeV)	110	115	120	125	130	135
Exp.	1.16	1.26	1.35	1.64	2.12	2.81
Obs.	1.39	1.82	2.24	2.11	4.20	3.39

p-values: all channels combined



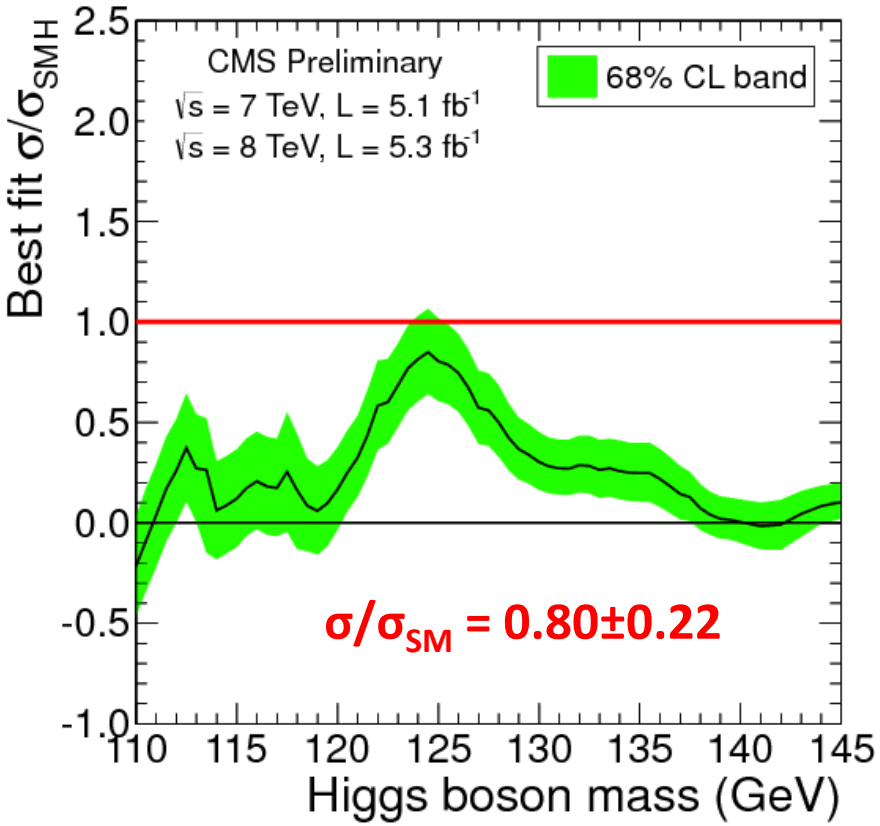
Local p-value combining all publicly available channels

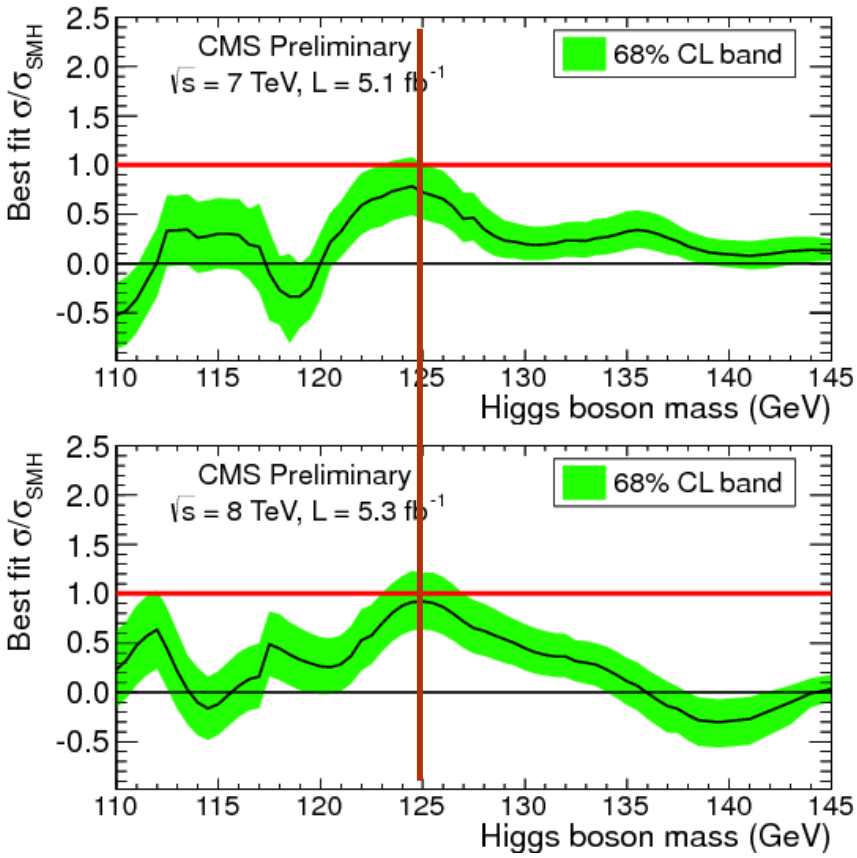
Local significance = 4.9σ

Adding fermion channels reduces the size of the excess

Could be fluctuations, or it could be telling us something

Combined Signal Strength





Overall consistency with the SM Higgs boson at 125 GeV

Where do we stand?

Observation in CMS, and independently in ATLAS, of a new boson with a mass of roughly 125 GeV decaying to vector bosons

It is certainly looking and walking like the SM Higgs boson. Does it also quack like the SM Higgs boson? Some questions:

Does it couple to fermions? **Maybe!**

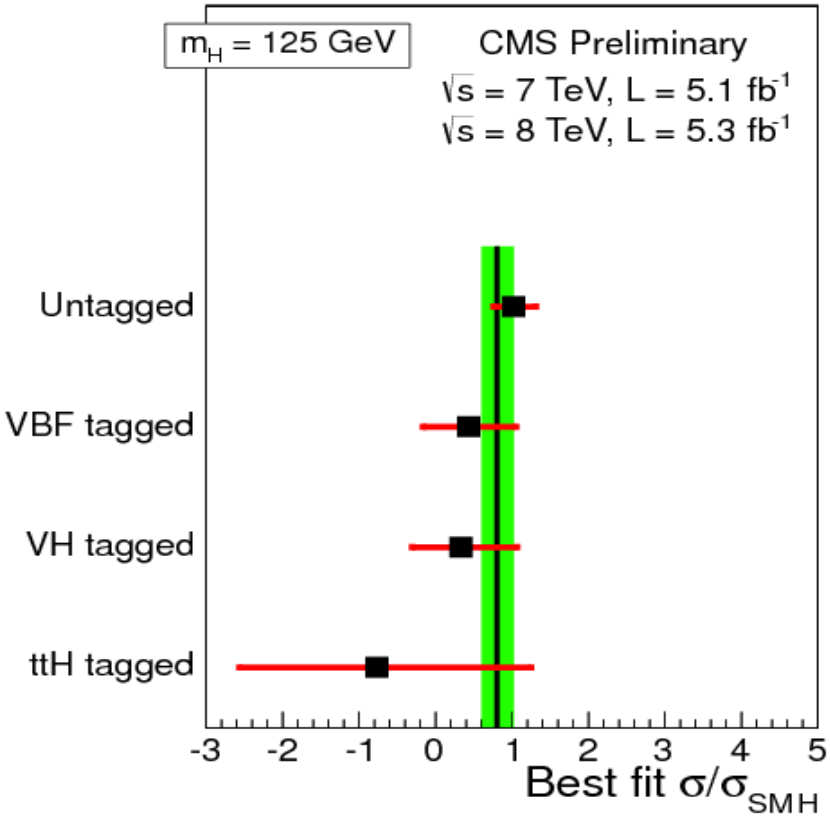
Is the width accounted for in the accessible channels? **Maybe!**

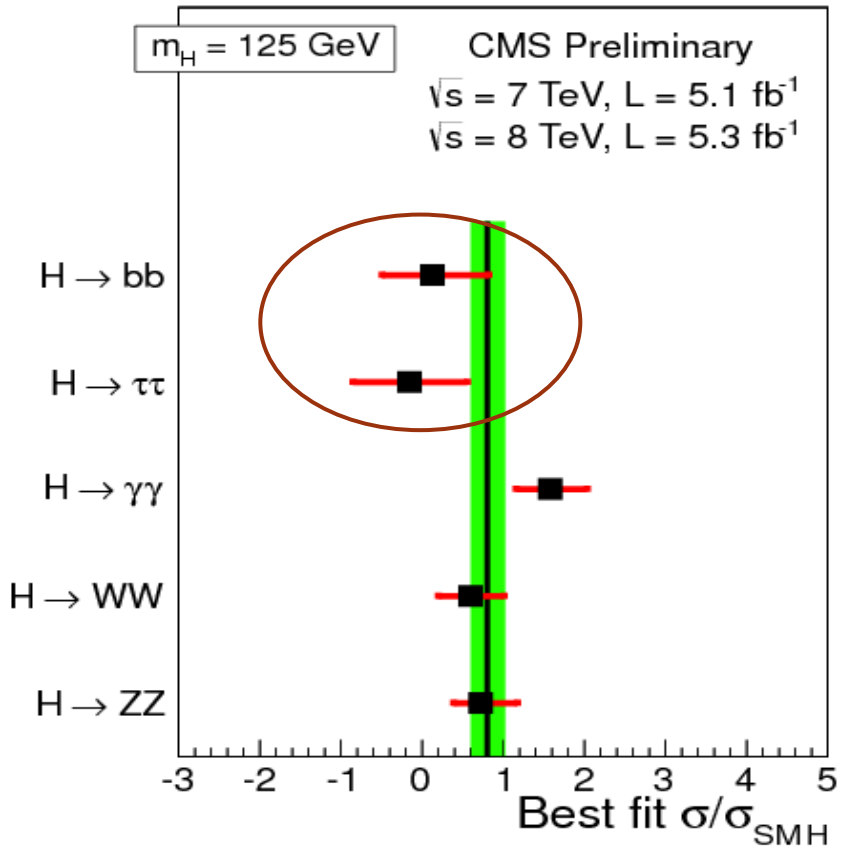
Are the relative signal strengths and couplings consistent?

We know it's a boson, we also know it is not spin 1. Is it spin 0?

If it is spin 0, is it a scalar or a pseudoscalar?

Signal Strength by Prod and Decay





Overall consistency, but fermion decays are a bit low

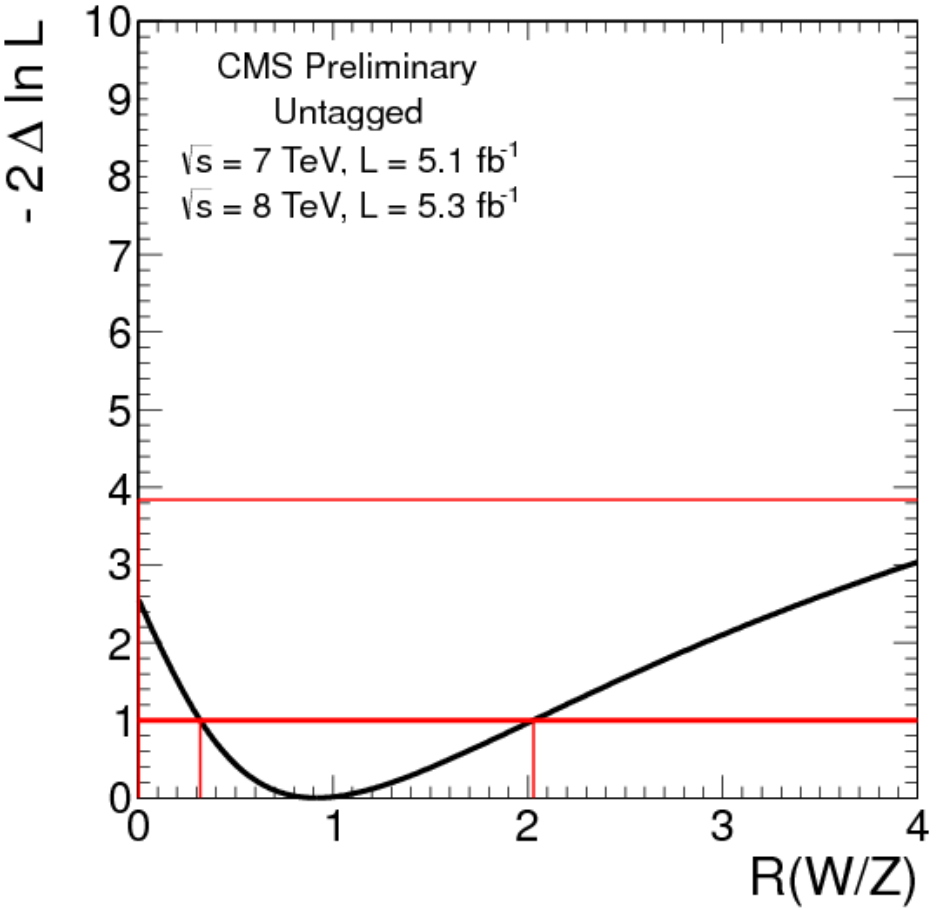
Ratio of WW and ZZ Couplings

Both dominated by gluon fusion production

Ratio of signal strengths is therefore dominantly the ratio of couplings to W/Z

Separate fit to WW and ZZ with M_H = 125.3 ± 0.6 GeV

$$R(W/Z) = 0.9^{+1.1}_{-0.6}$$



Consistent with SM Higgs boson (R = 1)

Couplings to V and F

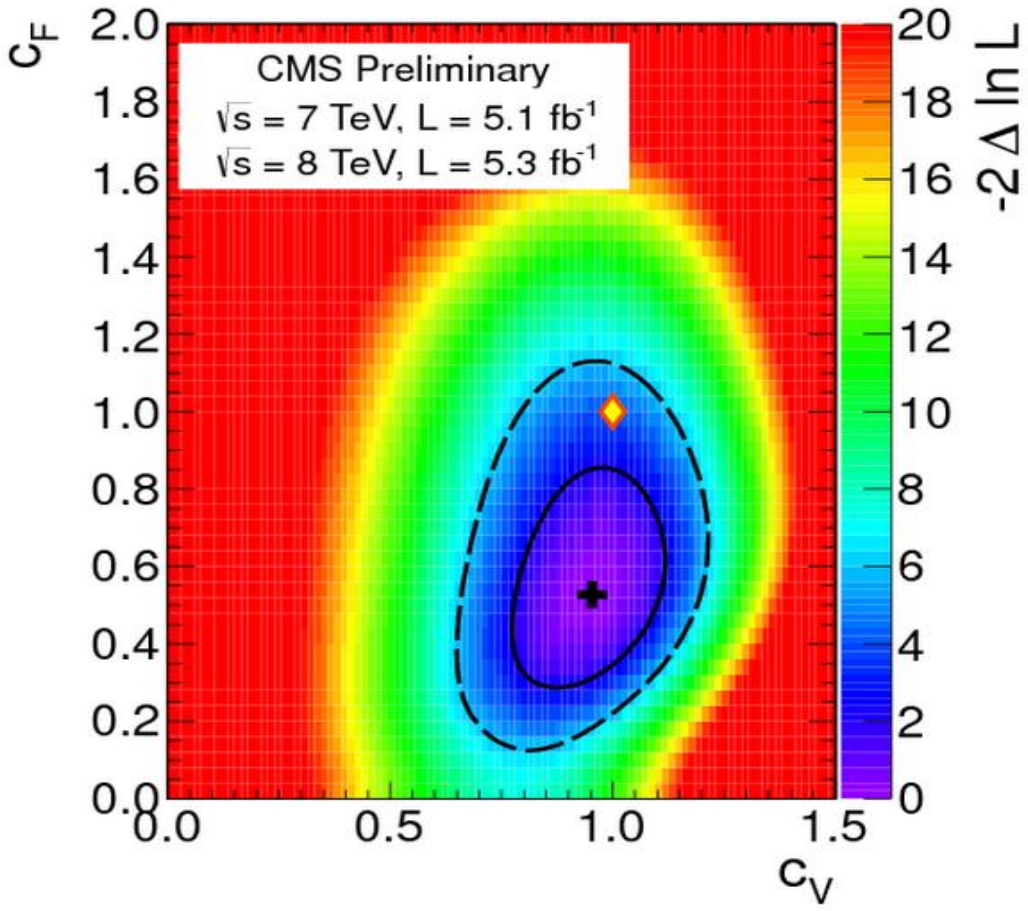
Group the Higgs couplings into "Vectorial" and "Fermionic" sets.

Assume that R(W/Z) = 1

Attach a modifier to the SM prediction to each of those (C_V and C_F).

Use LO theoretical prediction for loop-induced H → γγ, H → gg couplings.

In agreement with the SM within the 95% confidence range



Quite a few assumptions, need more data to make a definitive statement about couplings

Where do we stand?

Observation in CMS, and independently in ATLAS, of a new boson with a mass of roughly 125 GeV decaying to vector bosons

It is certainly looking and walking like the SM Higgs boson. Does it also quack like the SM Higgs boson? Some questions:

Does it couple to fermions? **Maybe!**

Is the width accounted for in the accessible channels? **Maybe!**

Are the relative signal strengths and couplings consistent? **Maybe!**

We know it's a boson, we also know it is not spin 1. Is it spin 0?

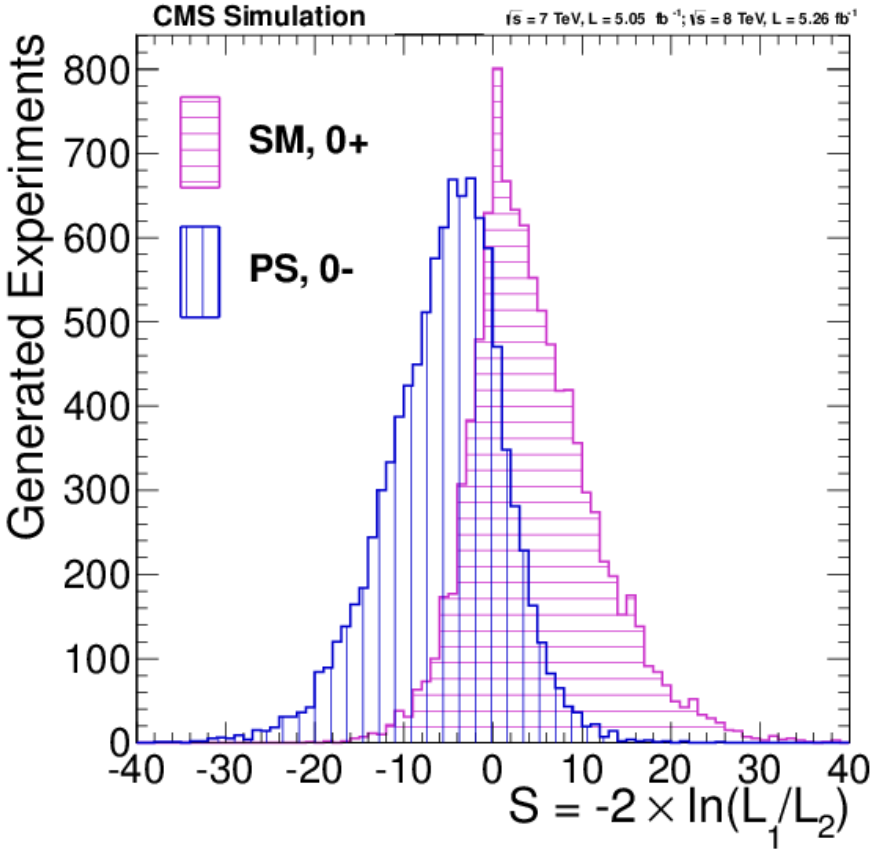
If it is spin 0, is it a scalar or a pseudoscalar?

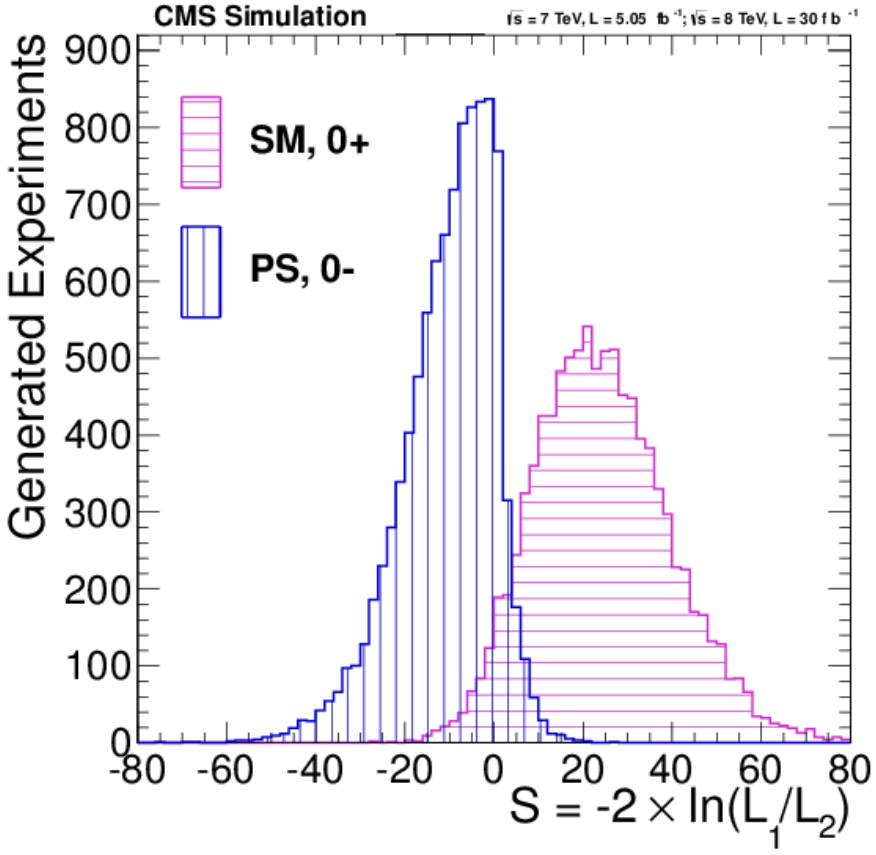
What can we say about spin?

ZZ^* channel provides best handle on spin determination

Unfortunately, at low mass, very difficult to separate spin 0 vs. 2

Some hope to separate scalar form pseudoscalar with final 2011+2012 data





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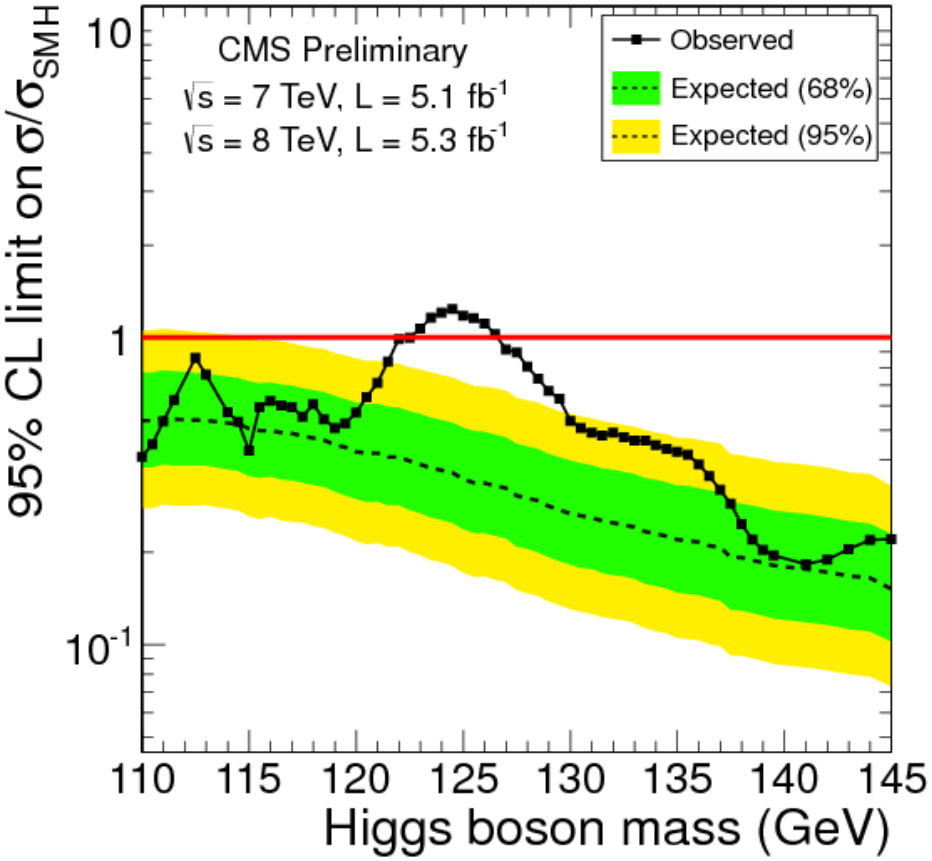
If it is spin 0, is it a scalar or a pseudoscalar? **Maybe!**

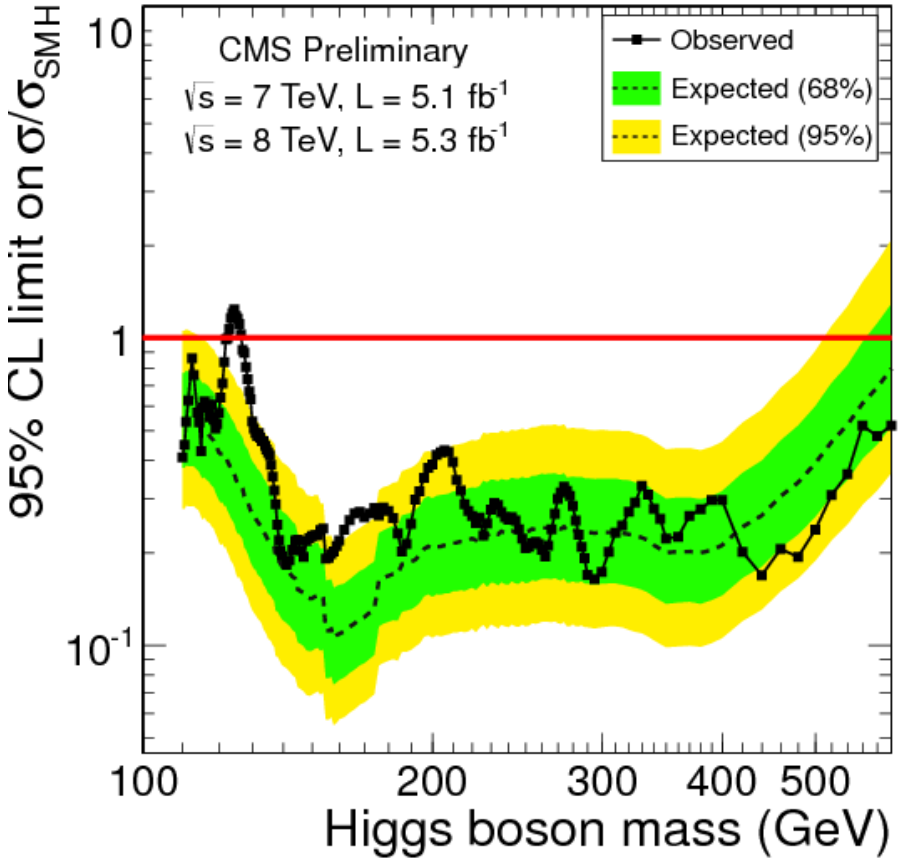
Lots of work still to do!

Conclusions

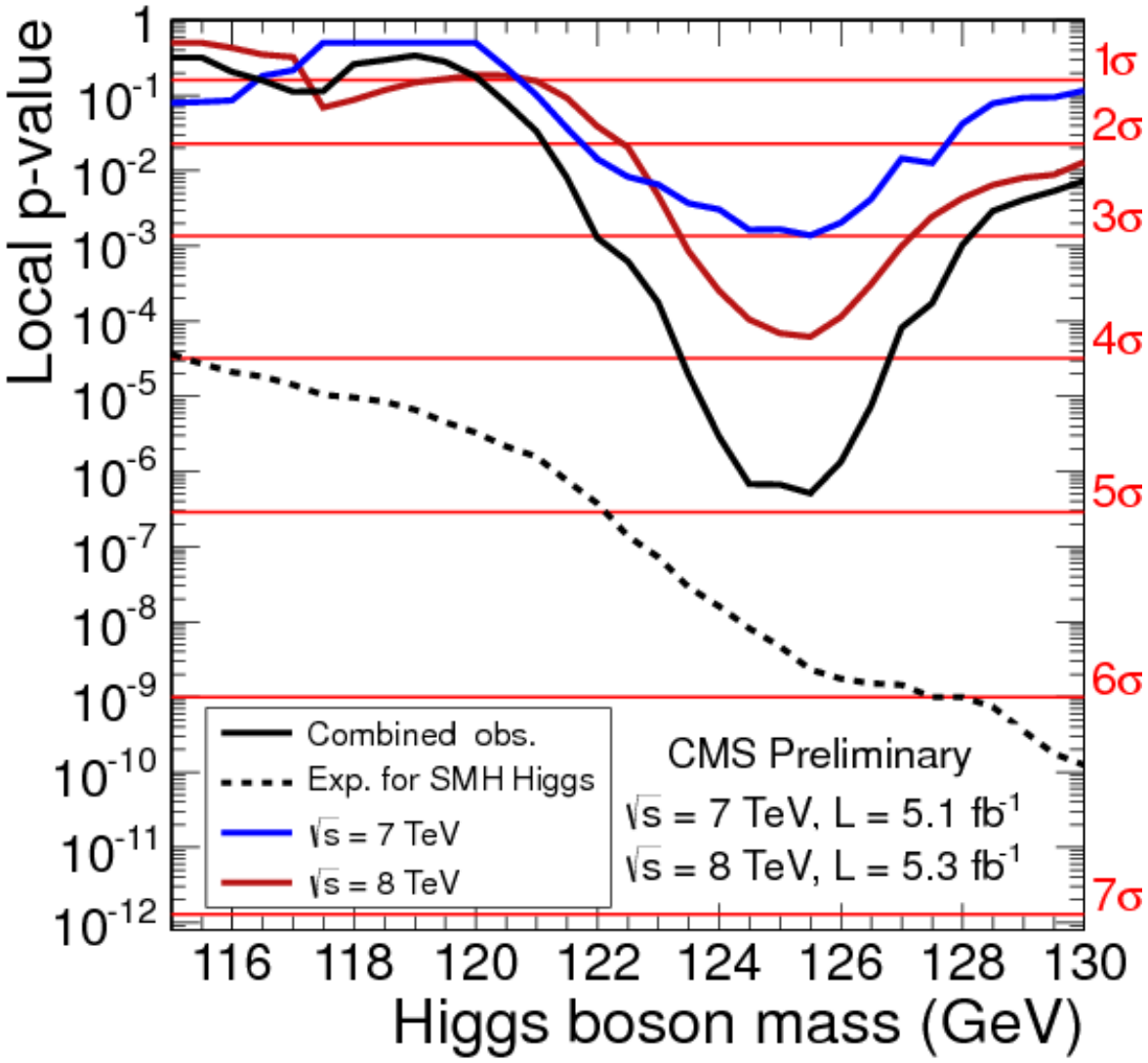
- LHC continues its outstanding performance
- We have observed a new boson decaying to gauge bosons with a significance of 5σ
- The mass of the new state is 125.3 ± 0.6 GeV
- While all current measurements are consistent with this particle being the SM Higgs boson, much more data is needed to falsify alternatives

Combined Exclusion Limits

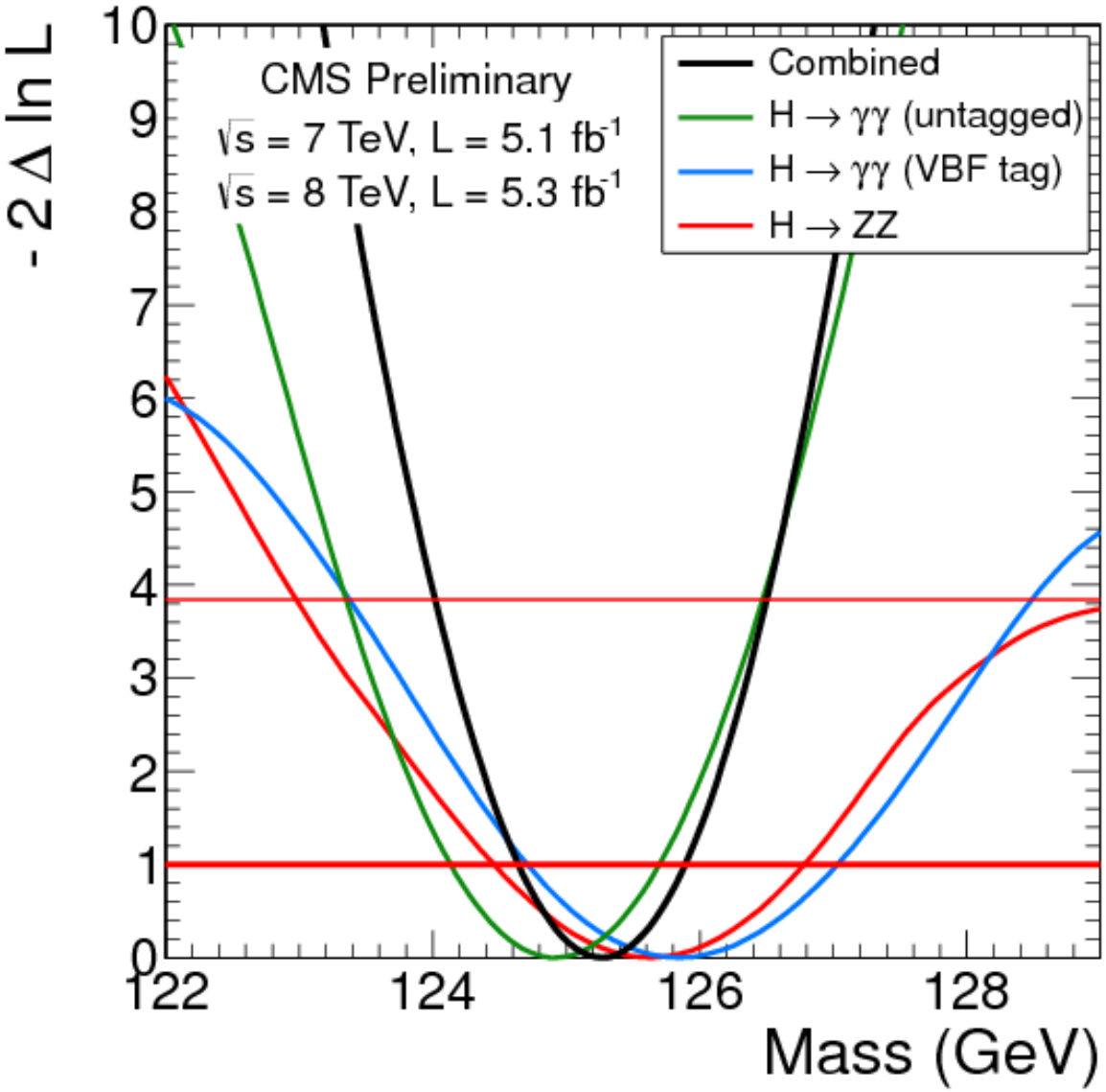




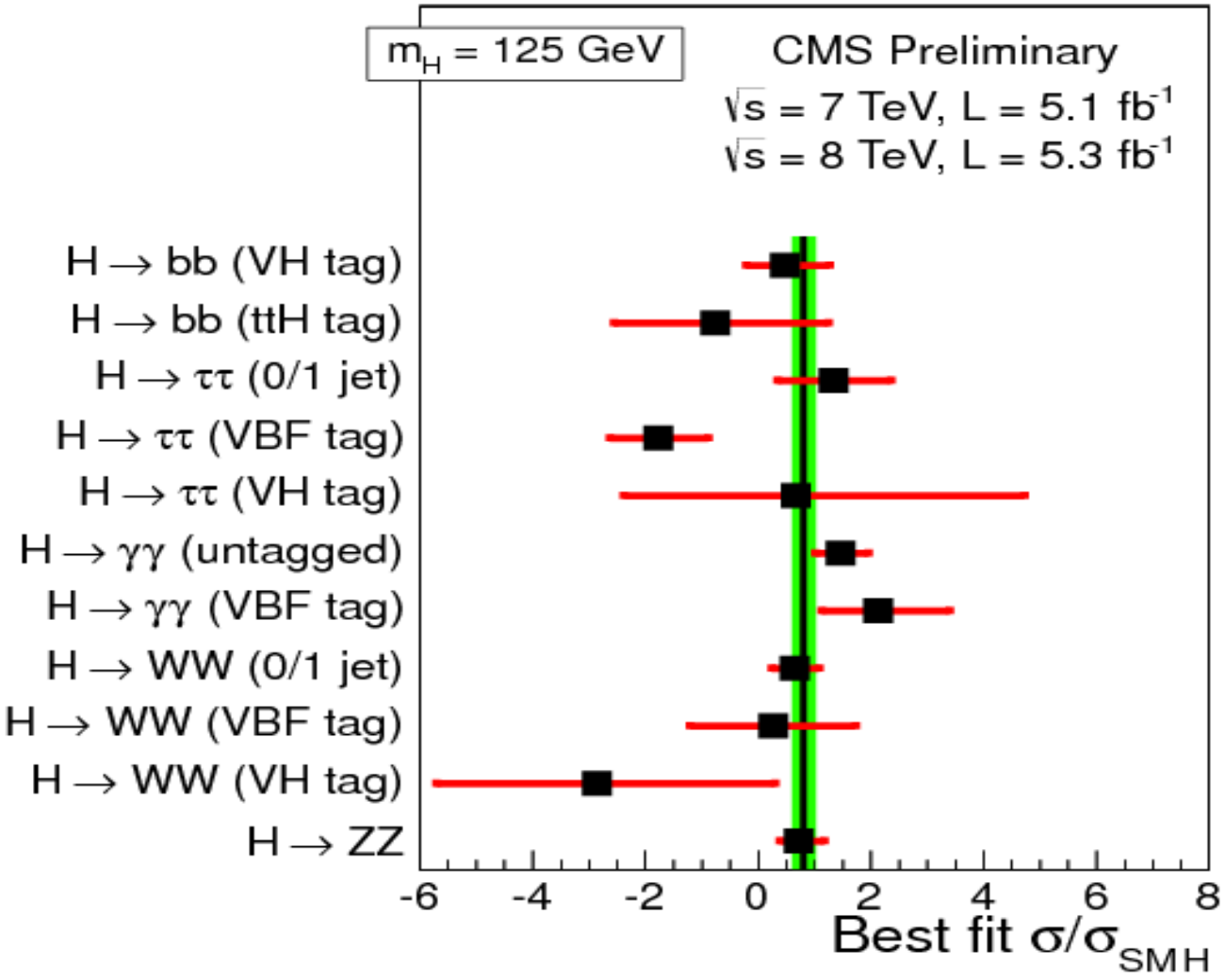
p-values: 7 vs. 8 TeV



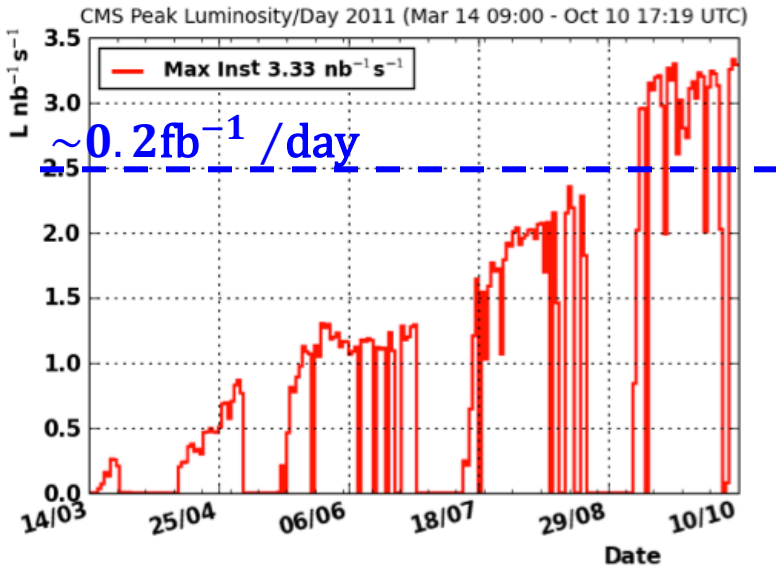
Mass Likelihood Scans

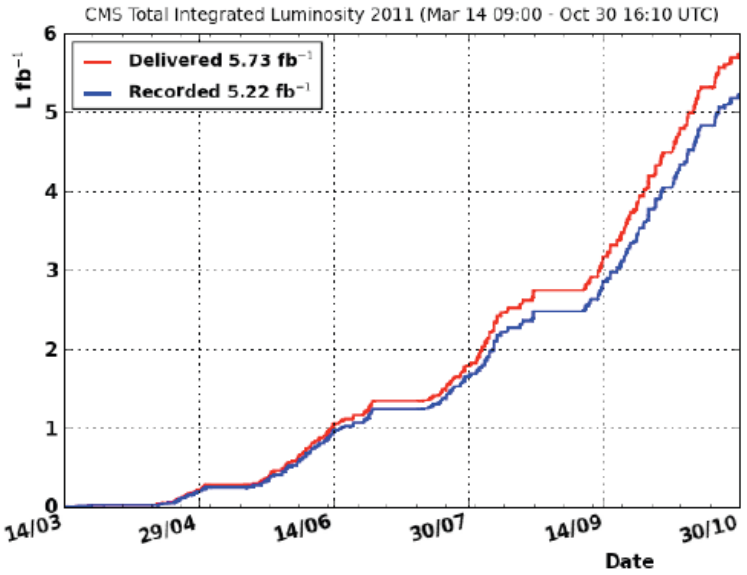


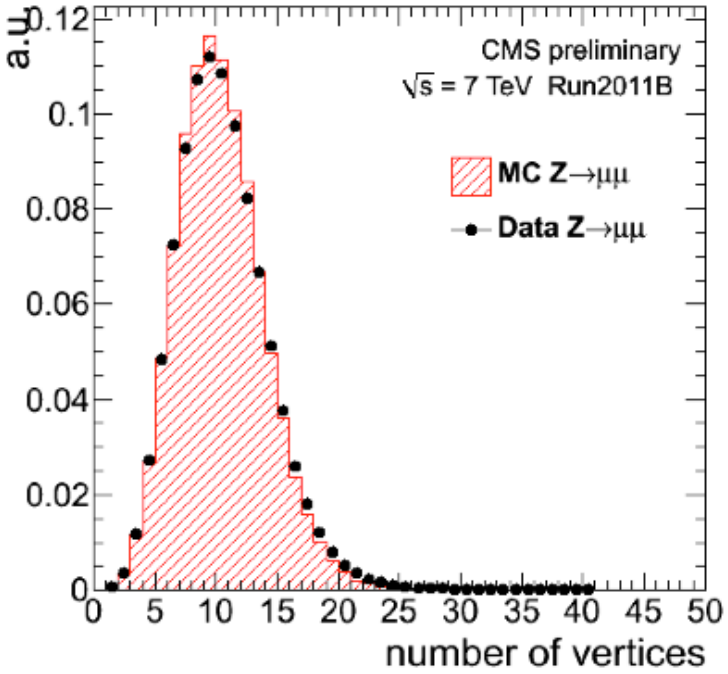
Signal Strengths by Mode/Category



LHC and CMS Performance (2011)







- peak lumi ~ $3.5 \times 10^{-33} cm^{-2} s^{-1}$
- > 5/fb recorded @ > 90% eff
- mean pile-up ~10, not a problem